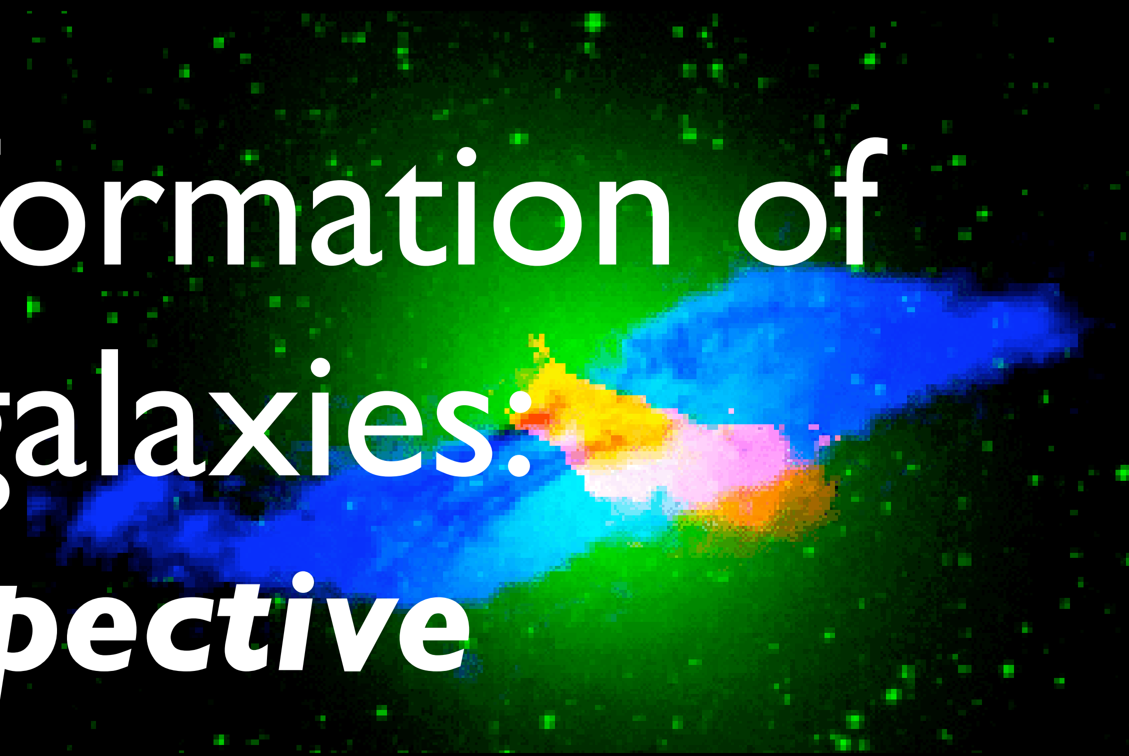
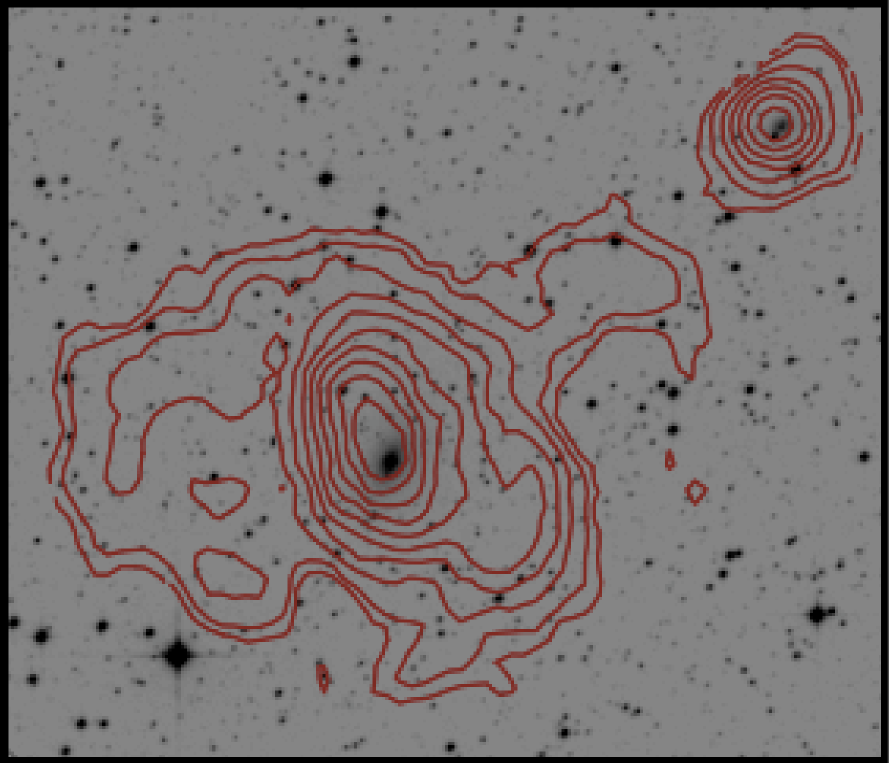


The continuing formation of early-type galaxies: ***an HI perspective***

Raffaella Morganti

ASTRON (Dwingeloo, NL)
and
Kapteyn Institute, Groningen



Gas as fossil record of formation and evolution of early-type galaxies

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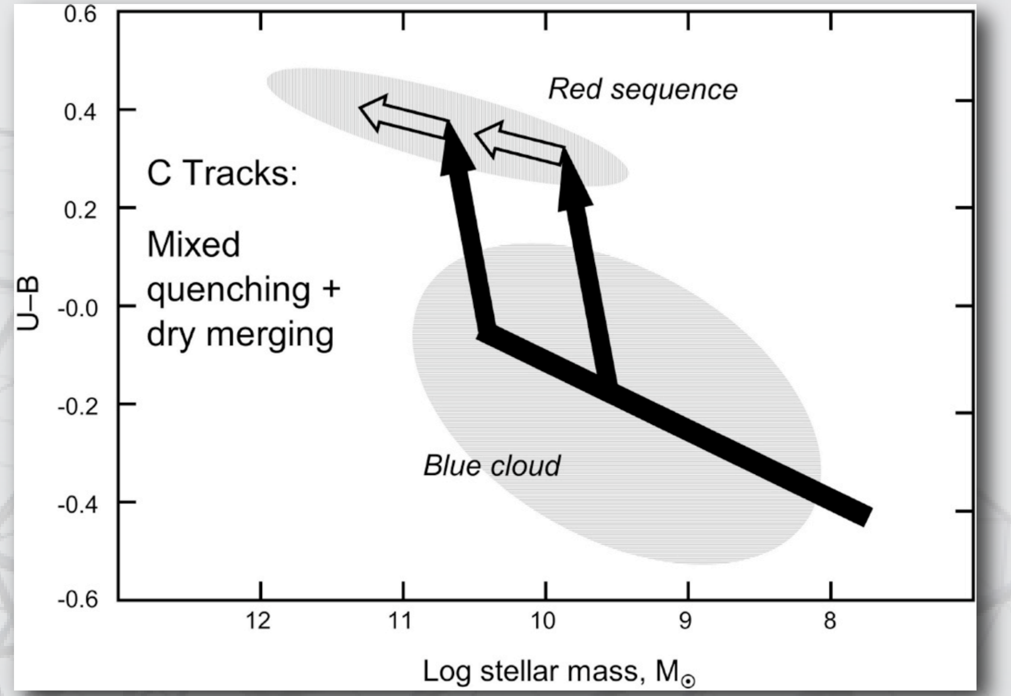


from Faber et al. 2007

NGC 7252 an elliptical forming now

shallow, deep and deeper images

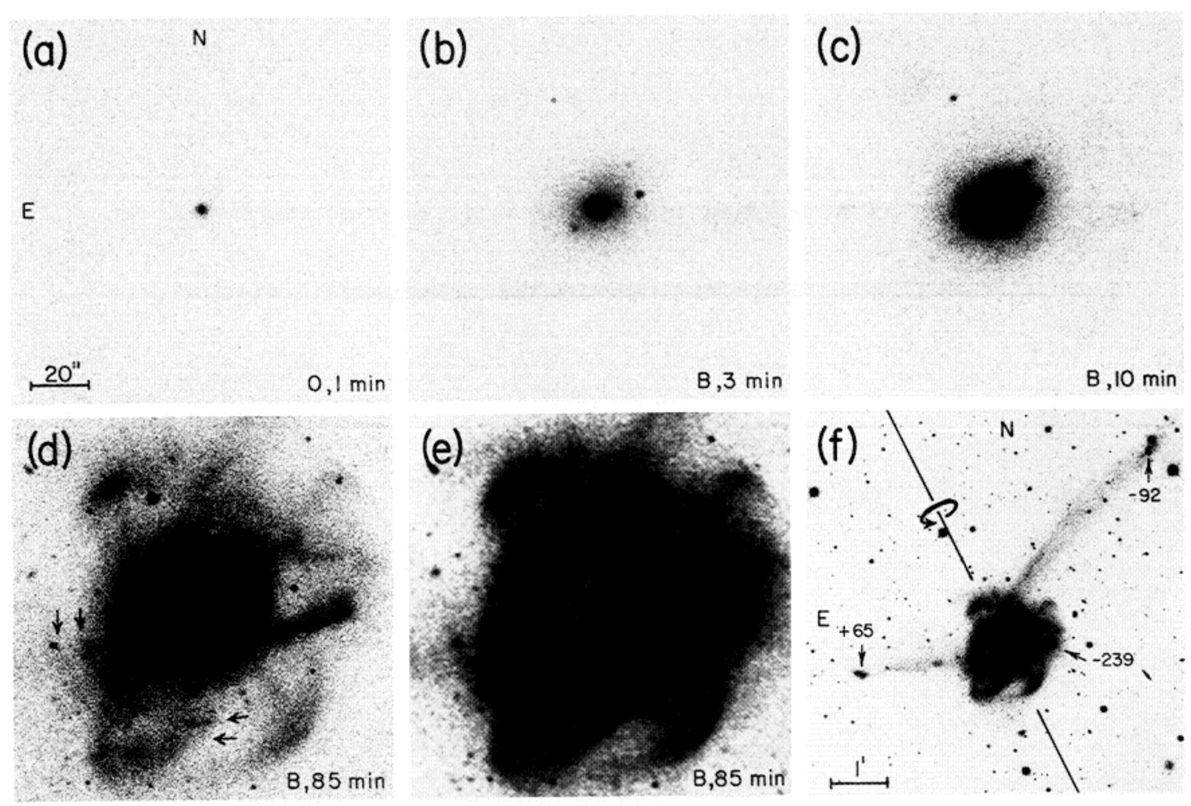
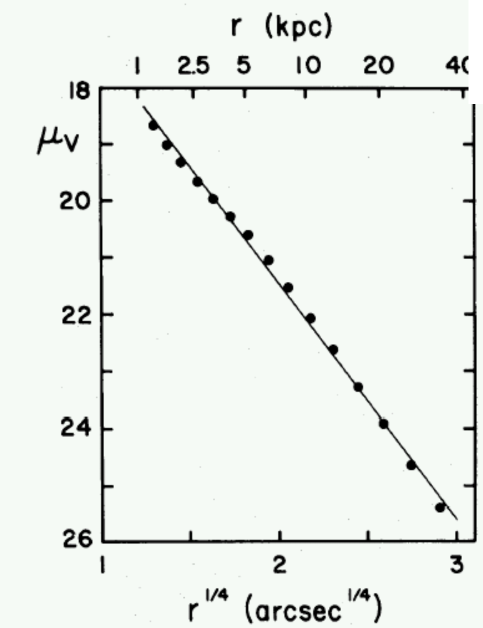


Fig. 2.—(a)–(e) Photographs of increasing exposure showing the nucleus, "fuzzball," and loops of NGC 7252; reproduced on a uniform scale [20″ bar in frame (a)] from orange (O: IIa-D+OG570) and blue (B: baked IIIa-J+GG385) plates obtained at the CTIO 4 m prime focus in 1″ seeing. Frame (d) has been dodged to better show the loops and delicate ripples (between *arrows*), whereas frame (e) shows a normal print. (f) Velocity map showing tail and loop velocities (in km s^{-1}) relative to the nucleus and the rotation axis of the inner gas disk.

SCHWEIZER (*see* page 455)

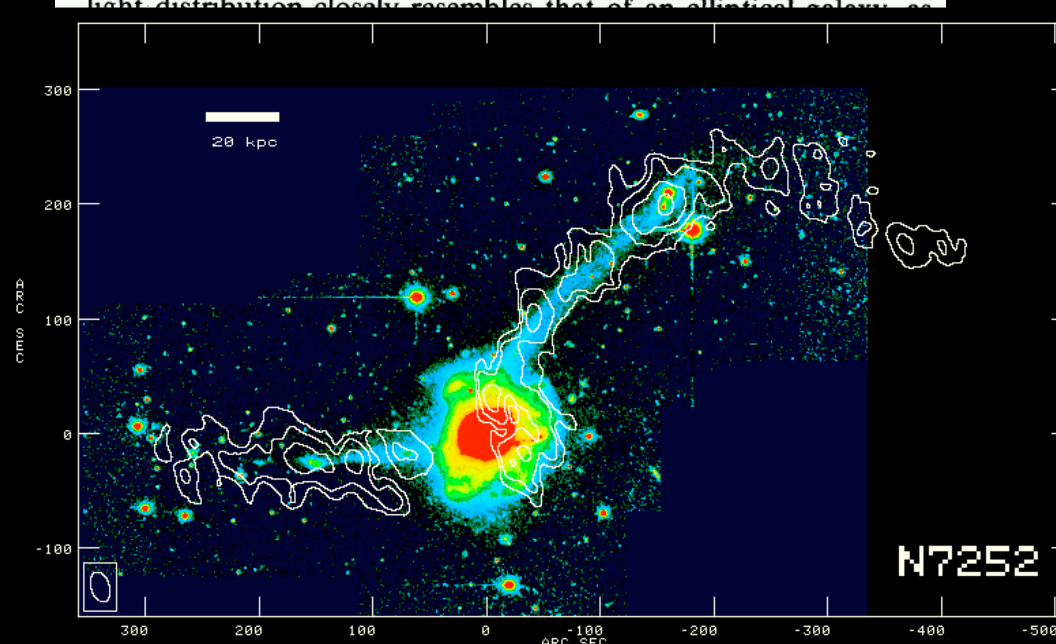
PLATE 11

Schweizer 1982



light profile is $r^{1/4}$

Fig. 6.—Radial light distribution of NGC 7252; visual surface brightnesses μ_V (in mag $arcsec^{-2}$) are plotted vs. the fourth root of the radius. The data points represent values calculated from the adopted growth curve of Fig. 5 by numerical differentiation. The



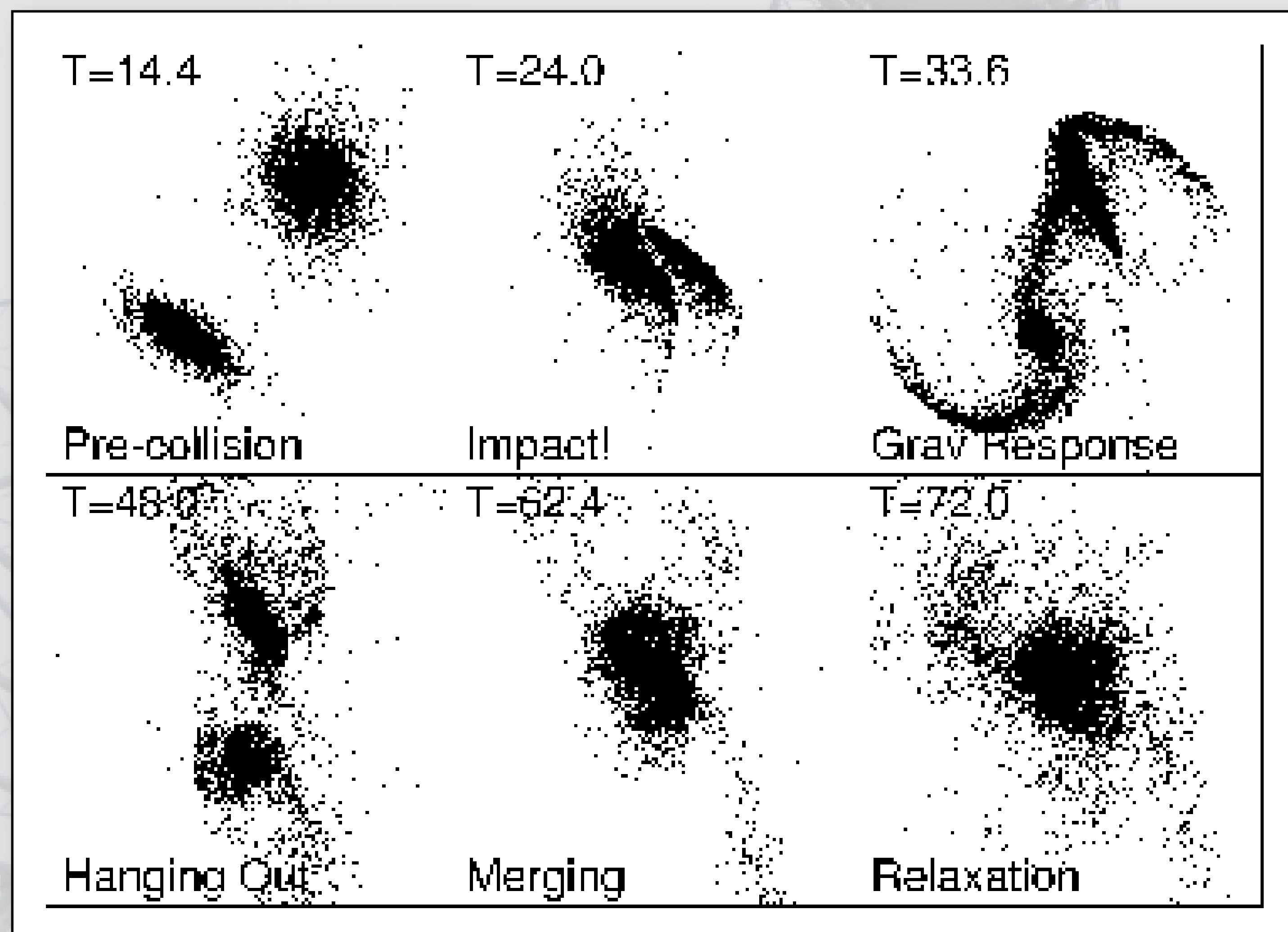
deep images reveal irregular features in outer regions

⇒ NGC 7252 is elliptical formed by gas-rich merger

H I (Hibbard et al.)

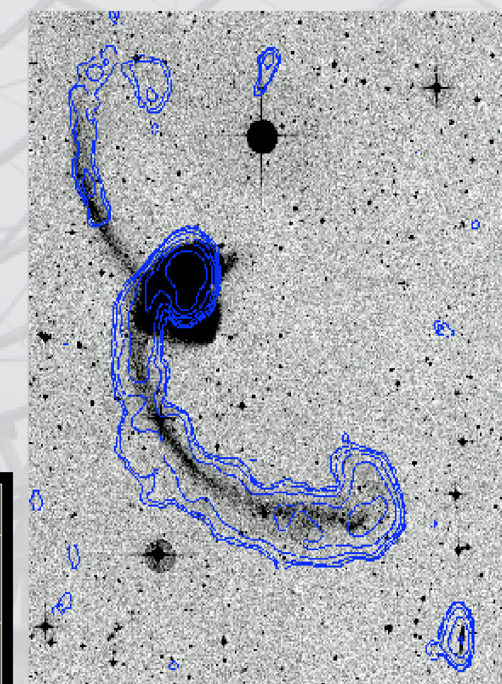
Formation of early-type galaxies from merger of disk galaxies: a lot of gas involved

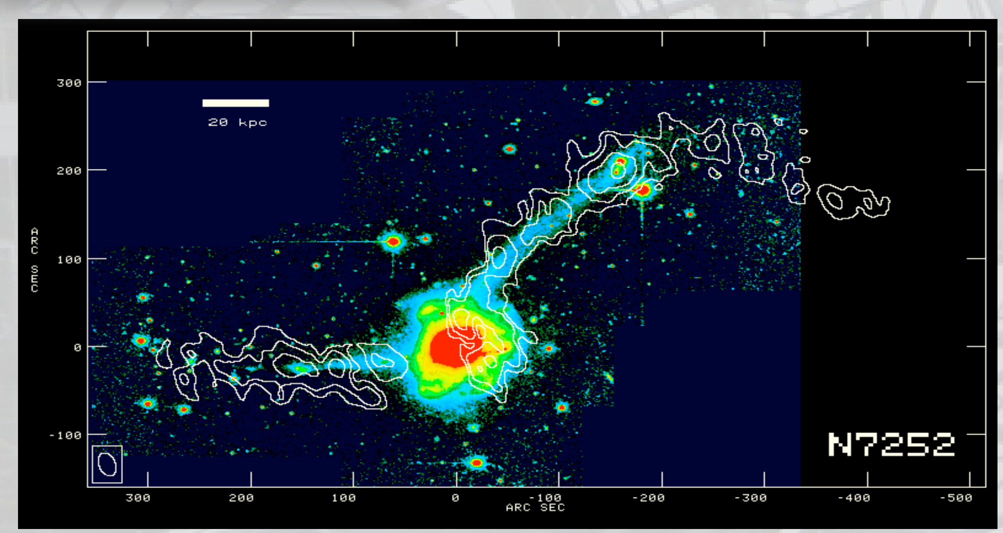
(Toomre & Toomre 1972 and many many other numerical simulations)



N-body simulations of a "typical" merger of two equal-mass disk galaxies resulting in an early-type galaxy (Mihos 1999)

Examples of distribution of the HI in the early stage of the merger





Hibbard et al.

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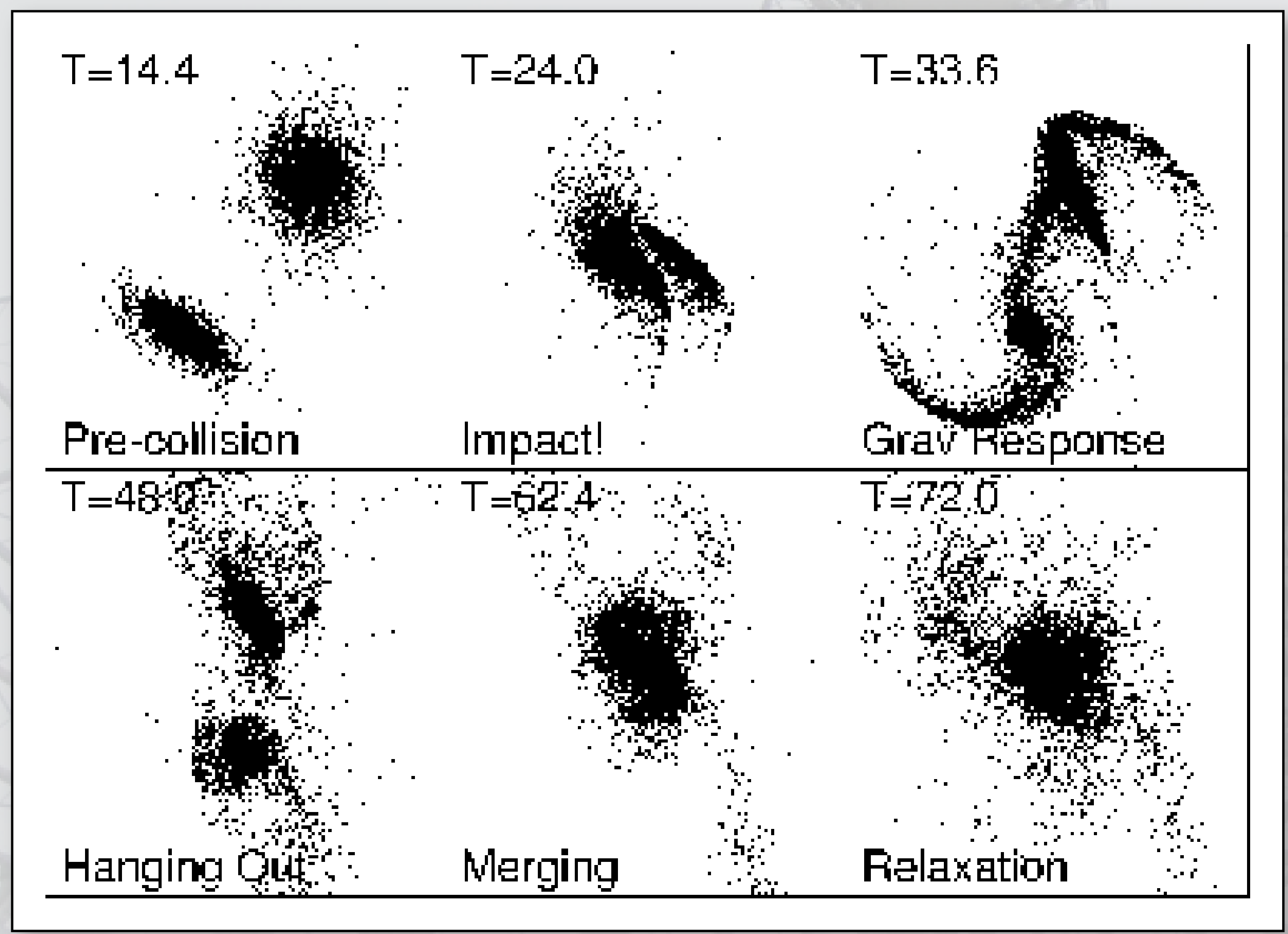

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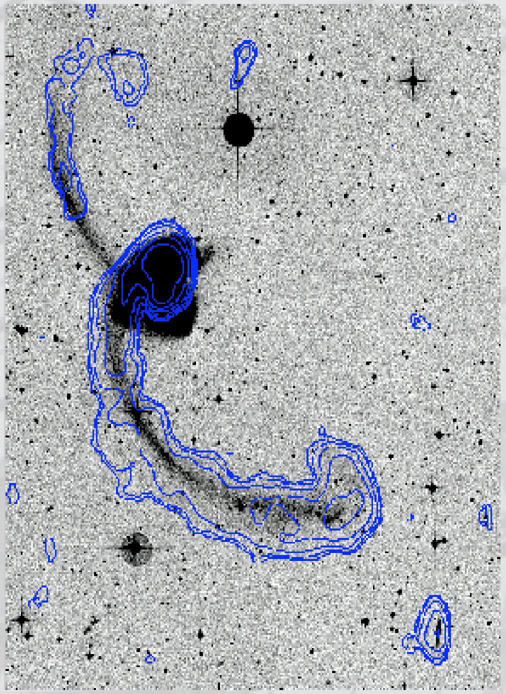
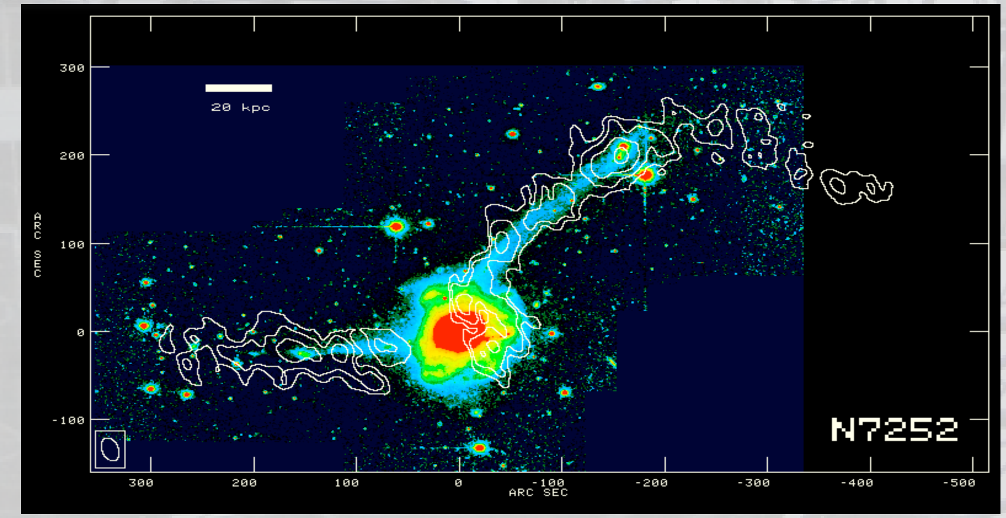




Hibbard et al.

Star formation also occurring: information on gas and stars needs to be combined to obtain the complete picture

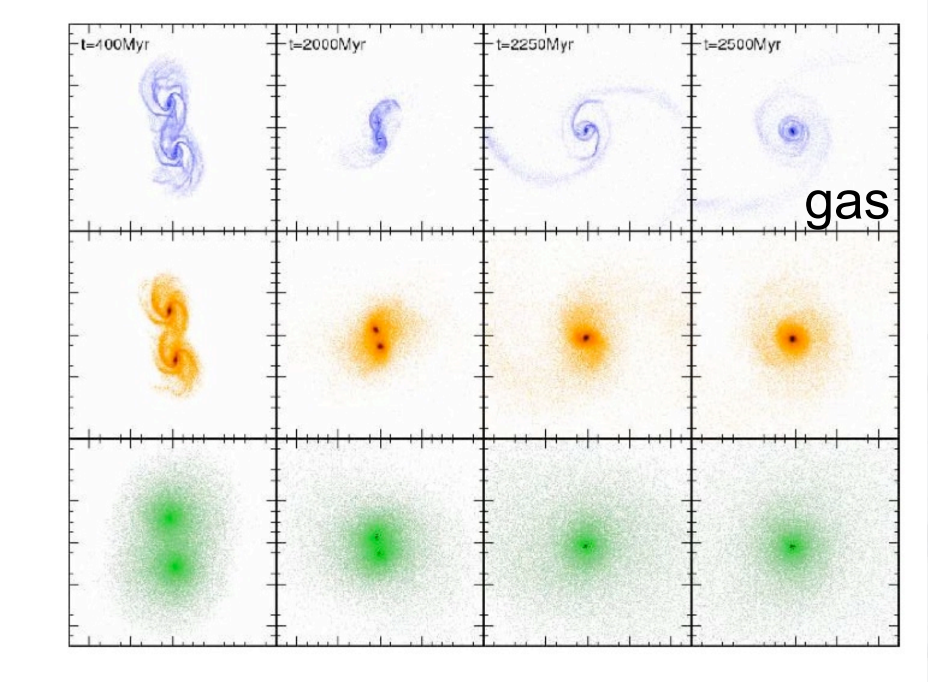
Predictions for stellar population

A significant fraction of early-type systems hosted low-level star-formation (at least few percent in mass) within the past few Gyr (see e.g. Trager 2000, Yi et al. 2005 etc.).

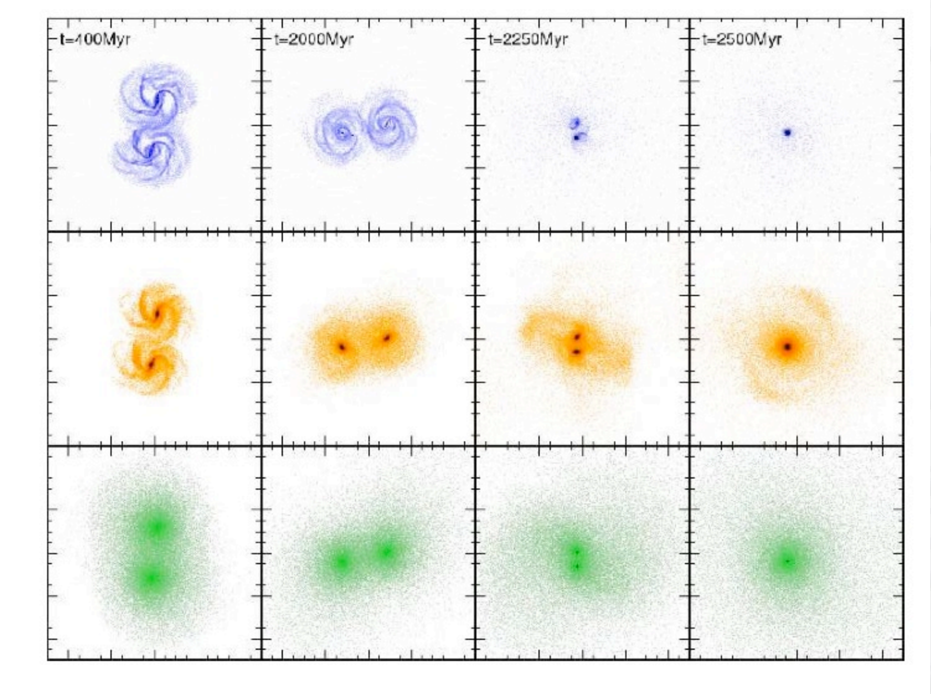
Star formation could have been triggered by merging activity.

⬇

relation between presence/absence of gas and star-formation?



Direct merger

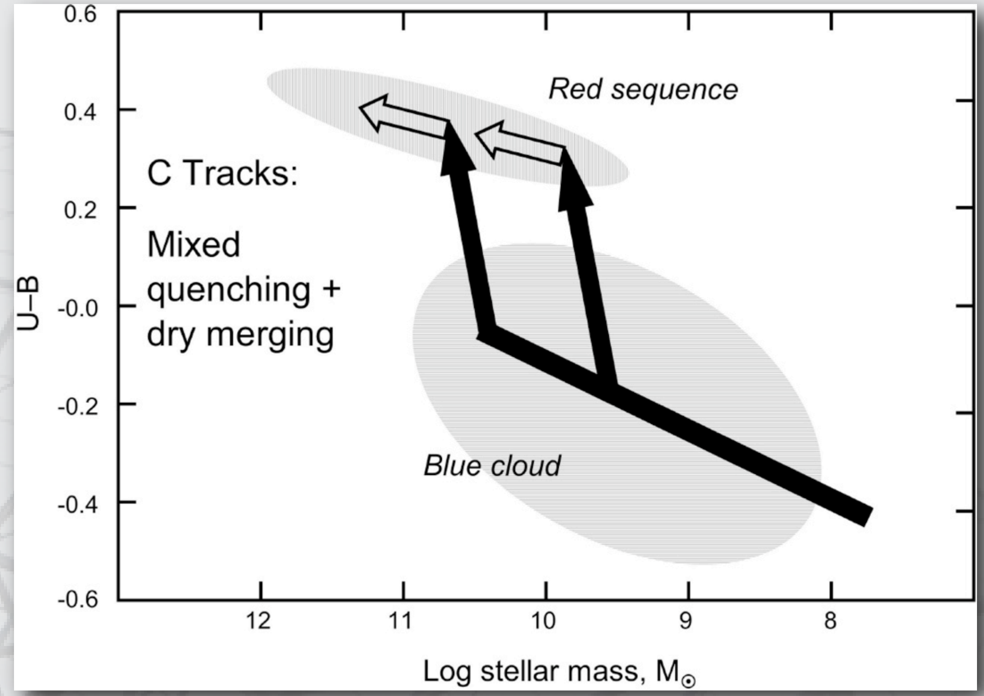


Retrograde merger: greater star formation efficiency

Di Matteo, Combes et al. 2007

Gas as fossil record of formation and evolution of early-type galaxies

- A possible scenario: **hierarchical growth of structures**



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↳ morphological transformation

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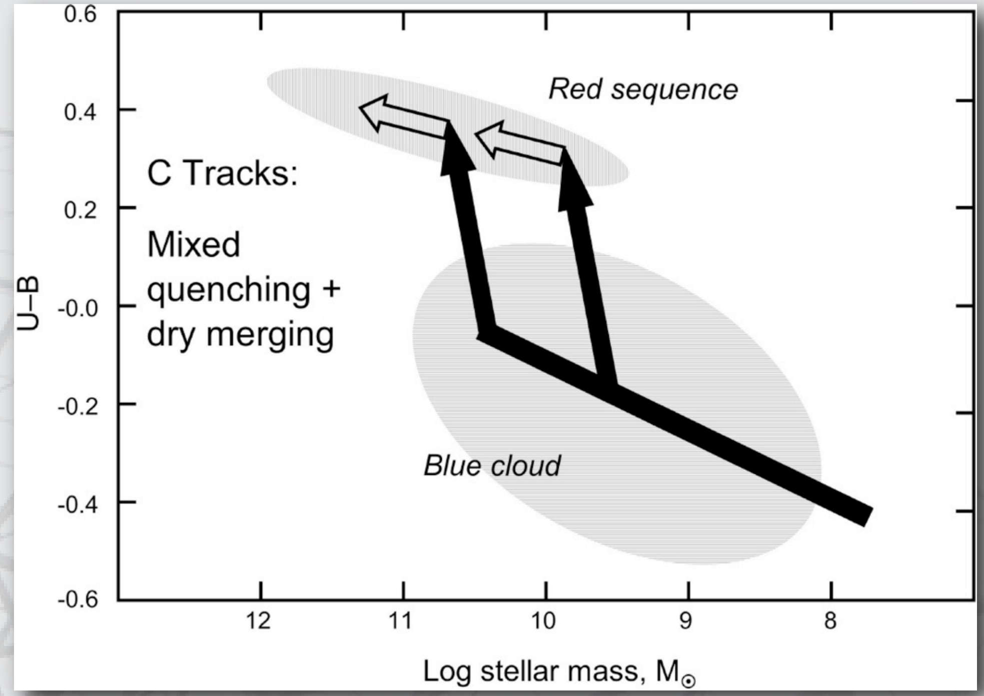

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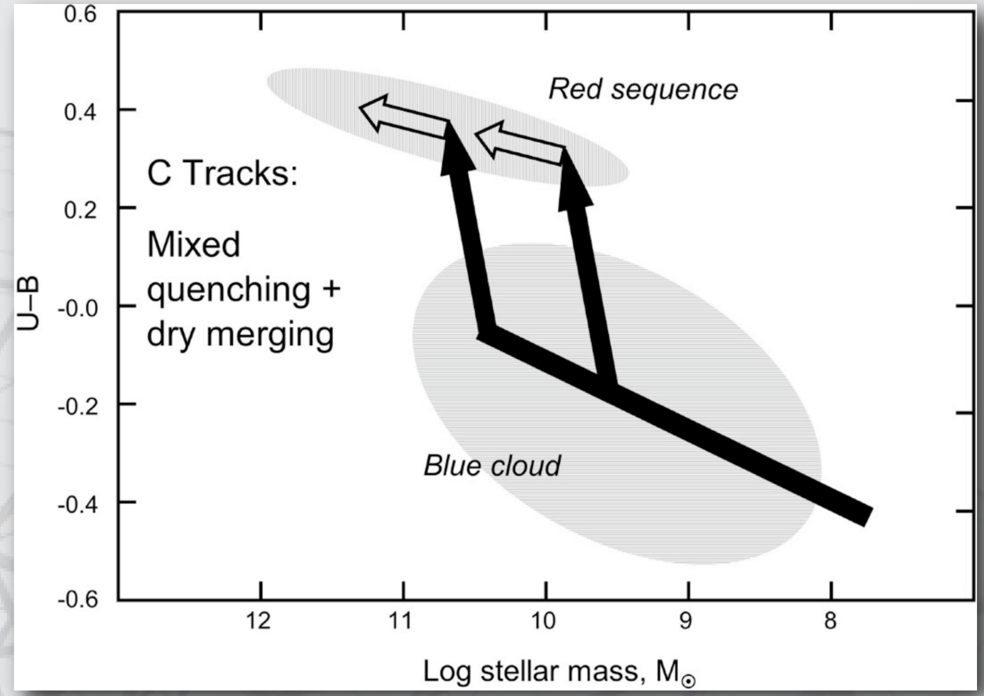

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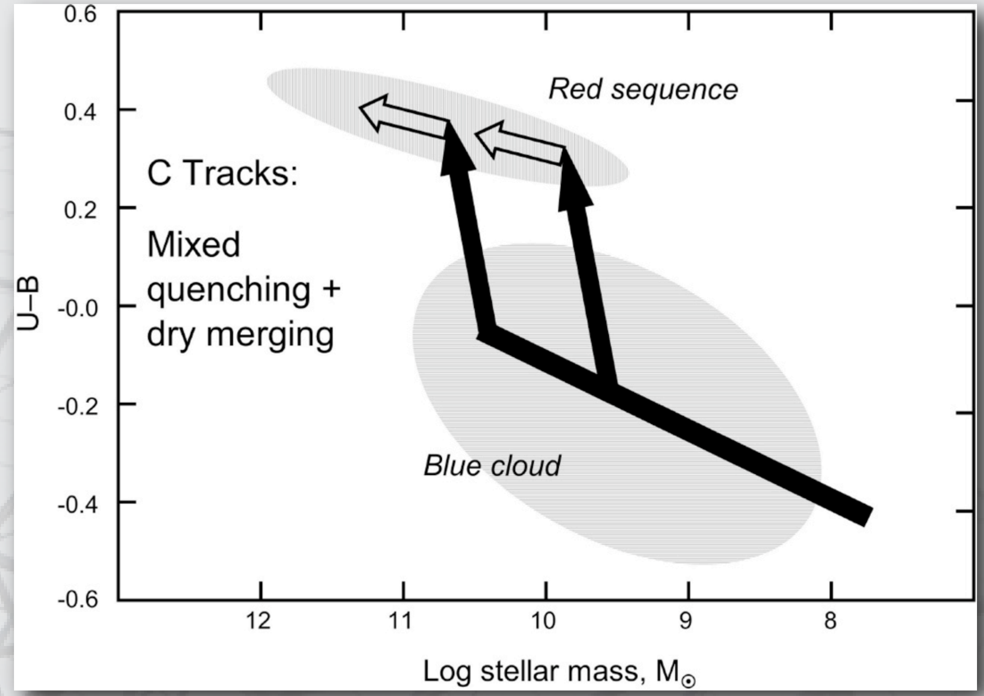

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BUT

- Dissipationless merger(dry mergers) also important?

  ↳ would they be responsible for systems with little or no rotation?

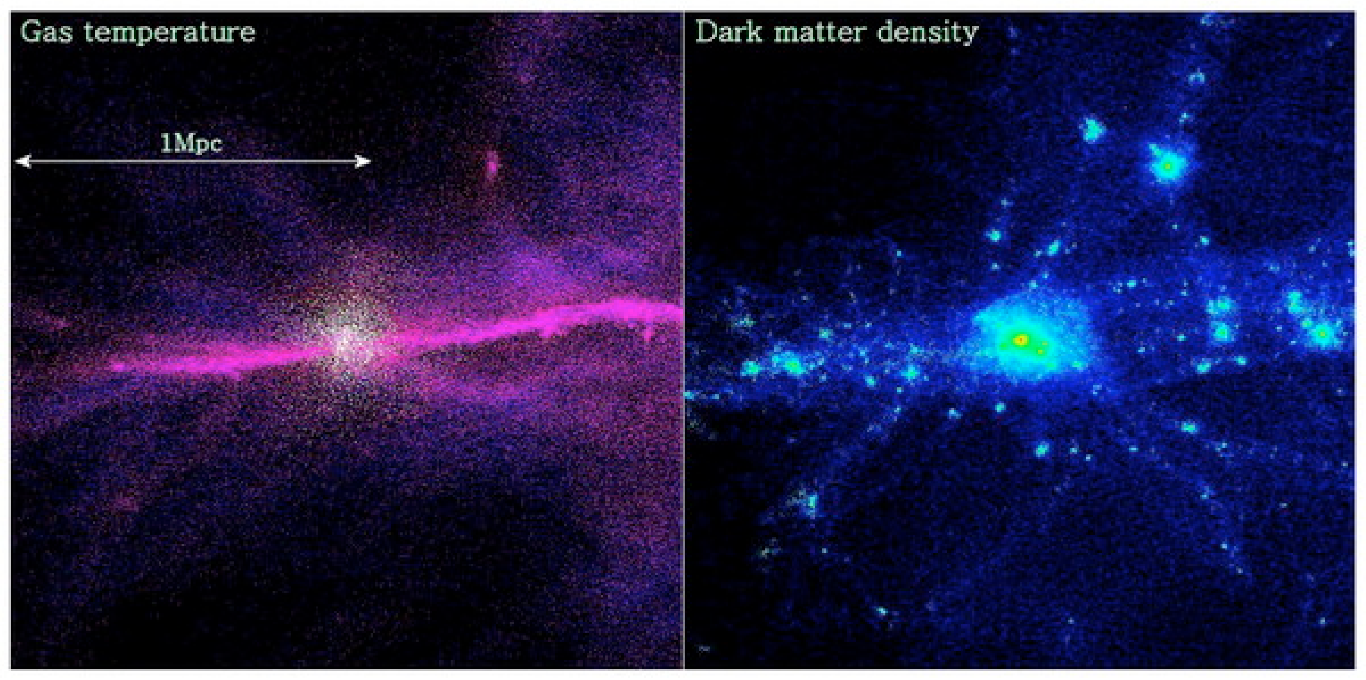
- How about cold accretion?

Cold accretion?

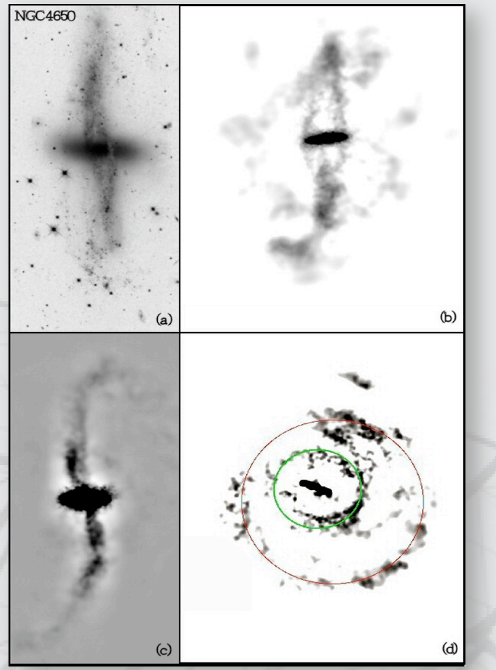
Slow but long-lasting accretion of significant amounts of (primordial) gas. Some of the gas can remain cool (not all gets shock ionised).

Keres et al. 2005, Birnboim et al. 2007

Not clear predictions about distribution and amount of HI but, unlike mergers, it should not leave a clear signature in the stellar population....



Macciò, Moore, Stadel 2006



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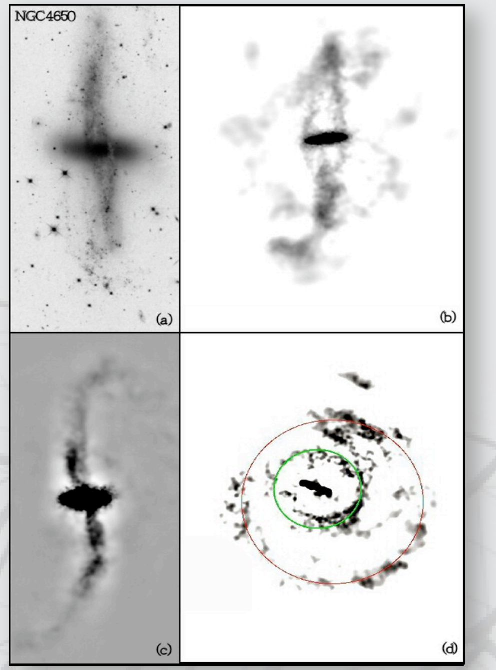

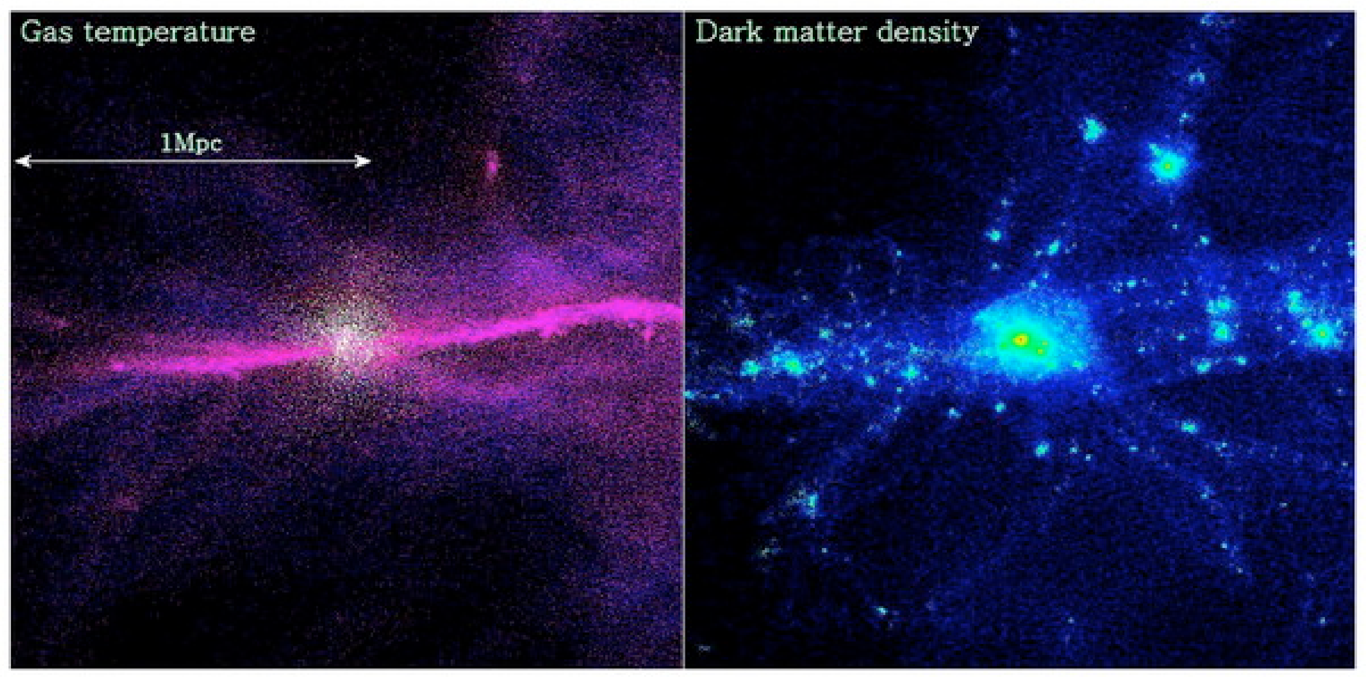

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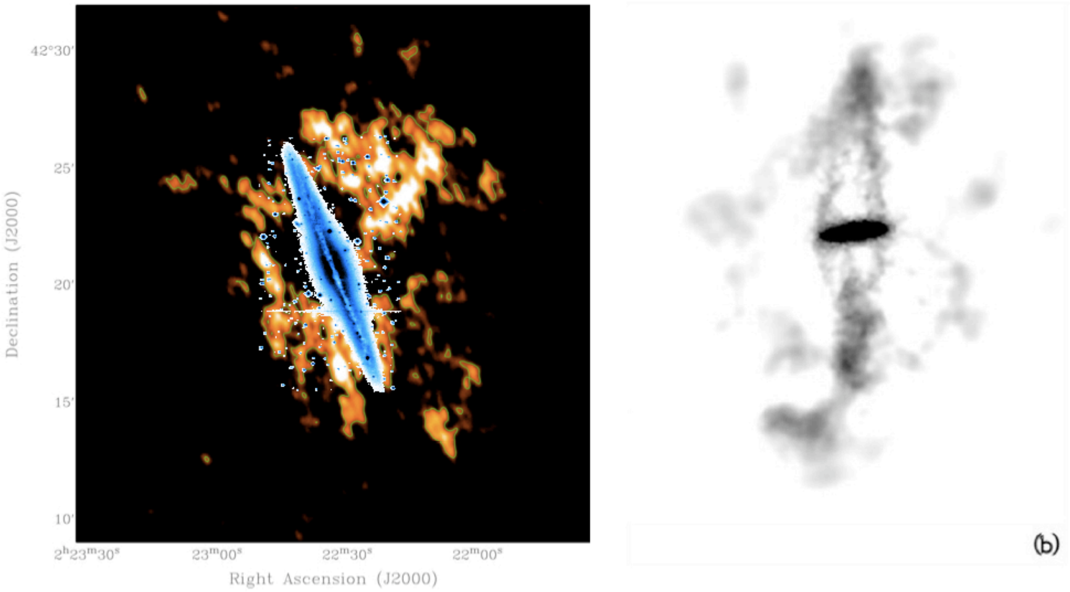

The gas falling onto NGC 891 as detected with the WSRT

Model prediction of accretion of primordial gas
(Maccio, Moore & Stadel)

Oosterloo, Fraternali, Sancisi (2007)

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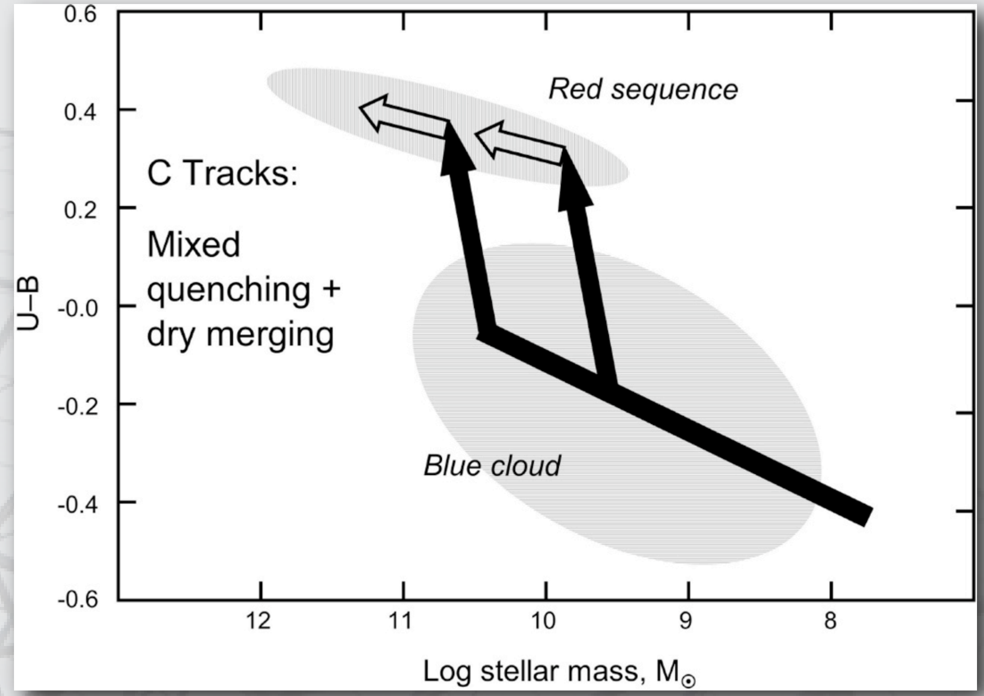

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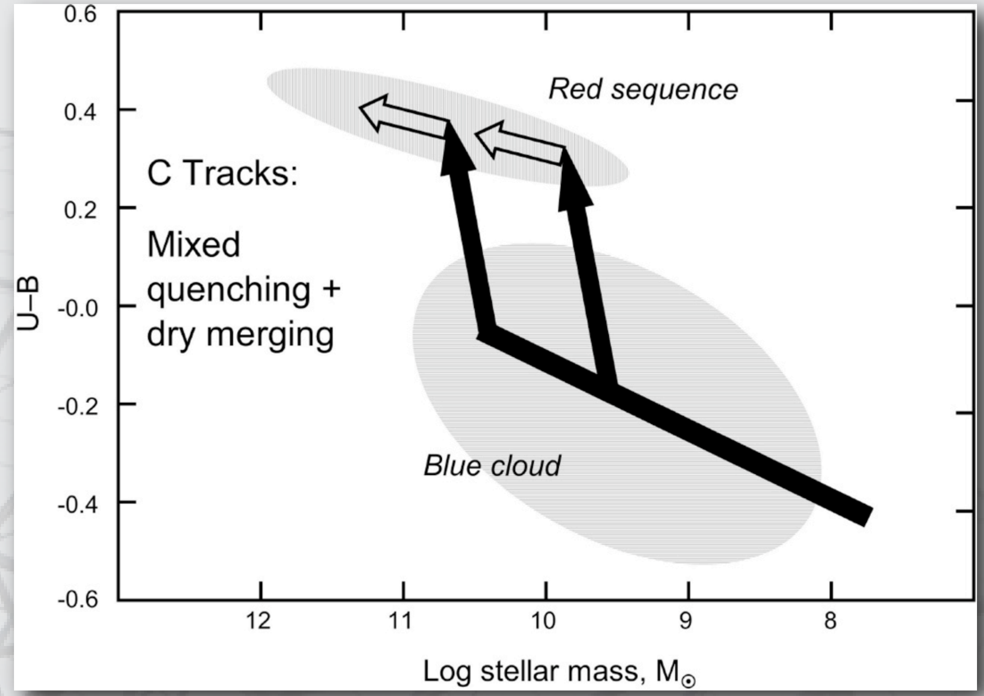

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BUT

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- How about cold accretion?
- **Role of AGN**
  - Mergers and AGN
  - Use the gas to trace the effects of the AGN
  - Identify the fuel

The effect of the active nucleus

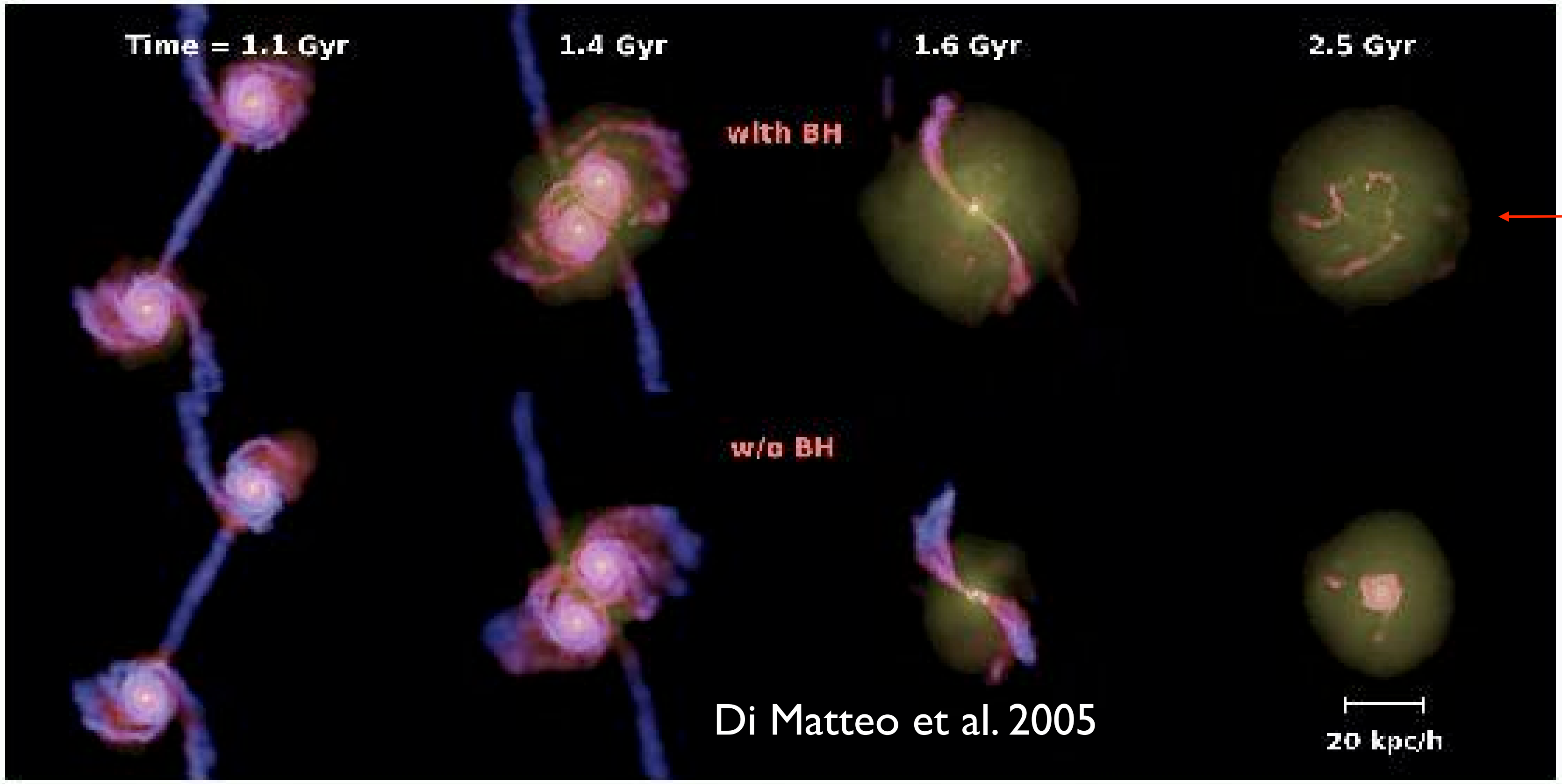
- Effect of nuclear activity on the ISM

Important for the evolution: inhibit starformation

→ correlation BH-host

Importance of AGN-driven outflows

Interplay between several ingredients: interstellar gas, star formation, growth of the massive BH



Starformation w and w/o central Black-Hole
Simulation with BH: after the final merging of the galaxies, a strong wind driven by feedback energy from the accretion expels much of the gas from the inner regions
→ gas poor remnant
Star formation suppressed by the presence of an active BH (di Matteo et al. 2005, Springel et al. 2005)

Why HI?

There are predictions from modelling that can be verified through HI observations.

- Morphology and kinematics of the HI: dissipative collapse after a merger can lead to the formation of disks while IGM accretion may lead more to filamentary, fragmented structures.

- Simulations of galaxy formation show that dissipative merger processes could be important for the emergence of oblate fast-rotating early-type galaxies as opposite to triaxial slow-rotators. Any relation between the presence of gas and the characteristics of the host galaxy (e.g. stellar dynamics)?

- Relation with other phases of the gas (e.g. CO and ionised gas)

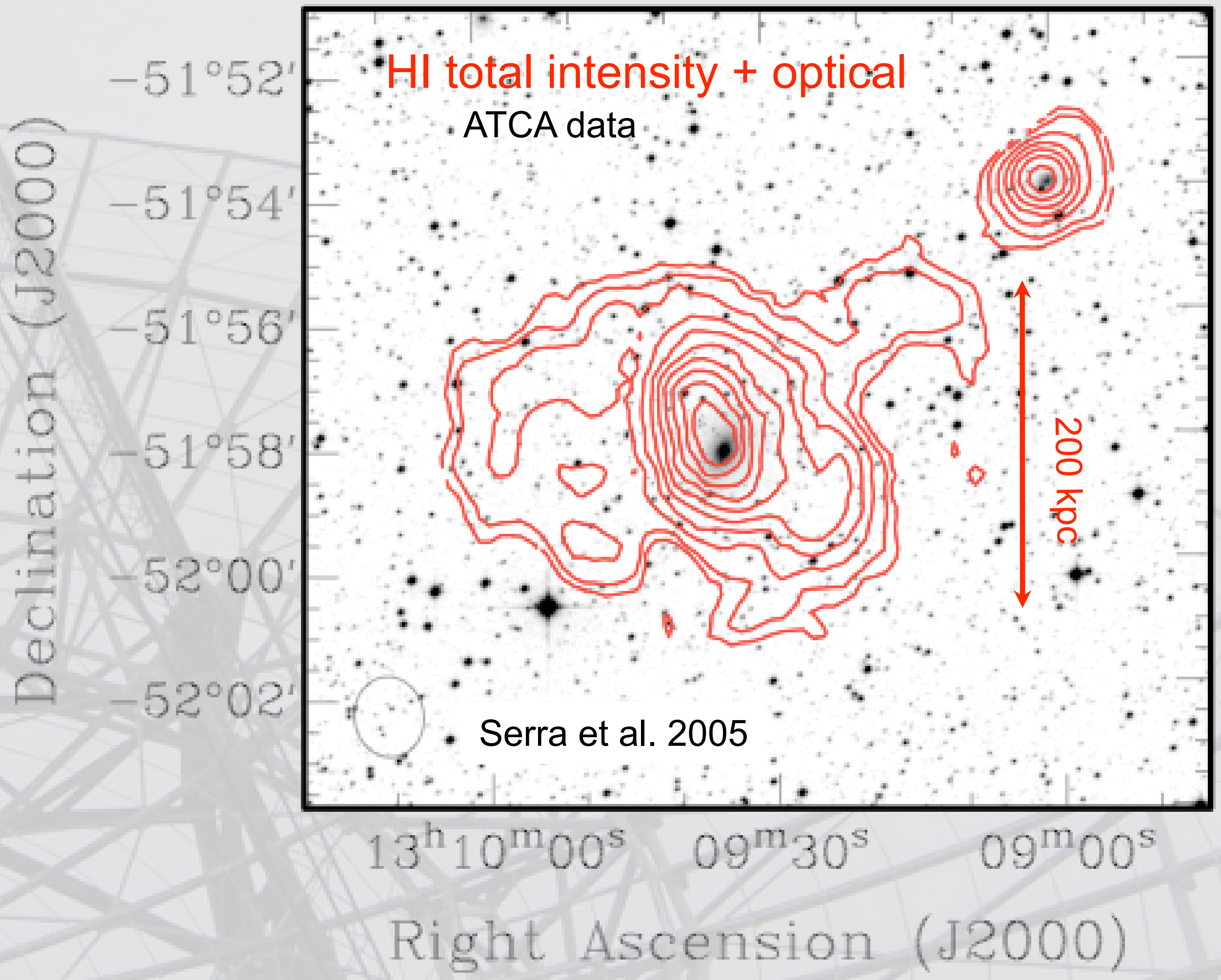
- Relation with star formation

- Relation between presence/characteristics of the HI and nuclear activity. Nuclear activity is often connected to merging/accretion. If so, this could be reflected in the HI properties
- Effects of the AGN on the HI?
- HI and feeding the monster?

HI in early-type galaxies: how often, how much (1)

- Tip-of-the-iceberg: HIPASS follow up
- 5-10% HI detections (> few x 10^9 $M_\odot$: more than in our Galaxy!)
- Morphology of the HI: majority regular, low surface density (few x 10^{20} cm^{-2}) disks/rings
- Stellar population - in some cases, stars and HI distribution indicate a major merger as origin

Oosterloo T., Morganti R. , Sadler E., Serra P. (2007)



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Paolo Serra PhD, Kapteyn Inst.

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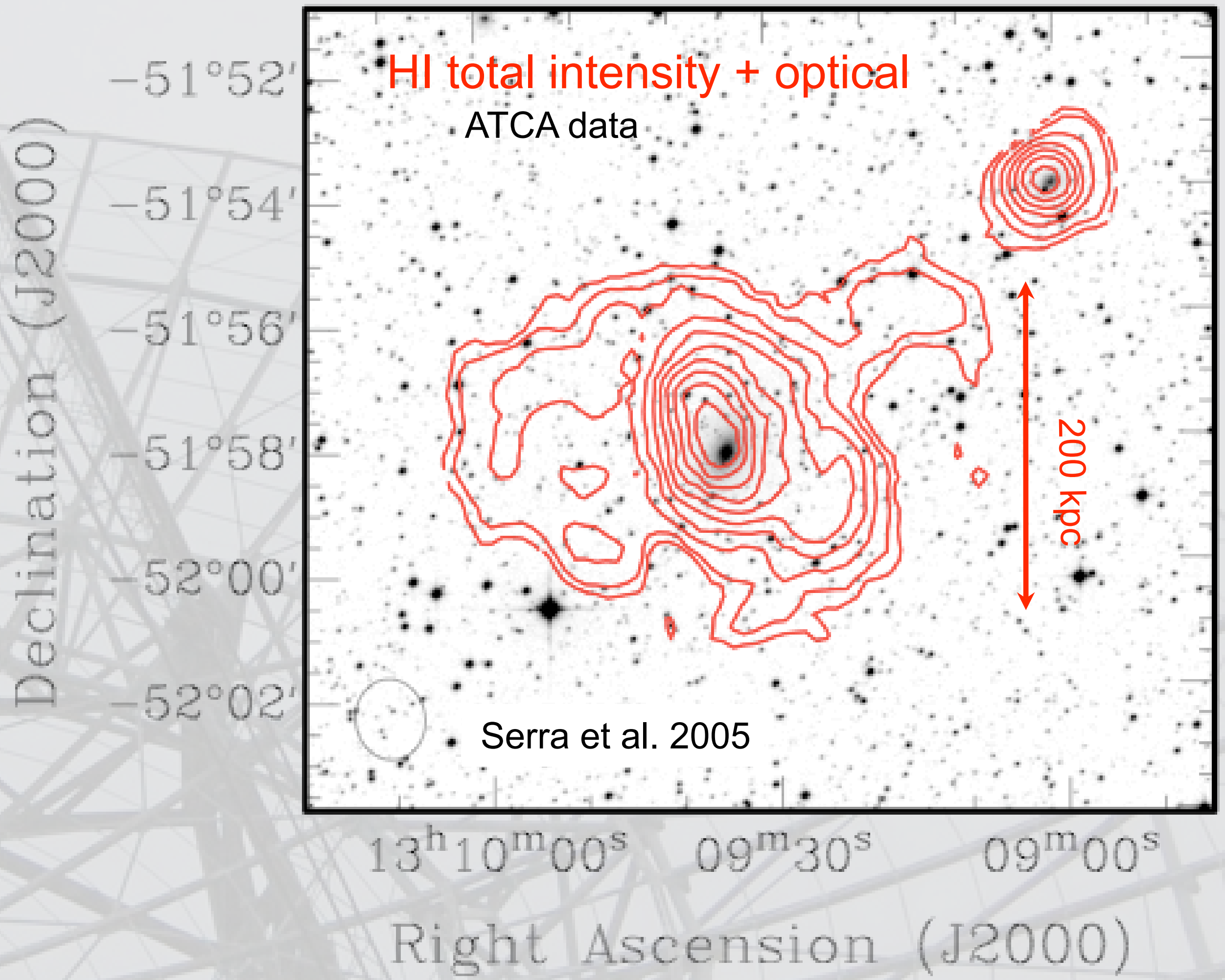

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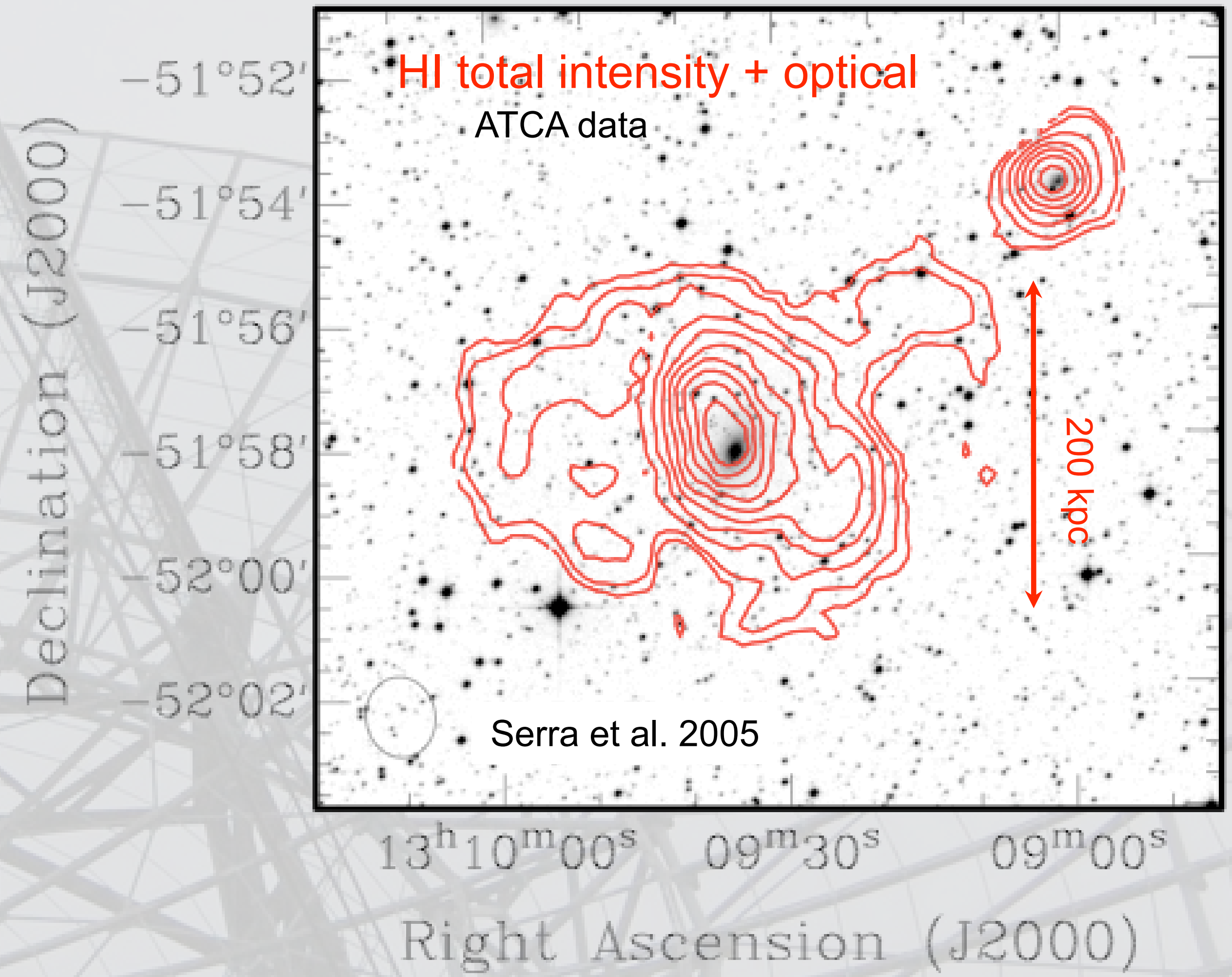

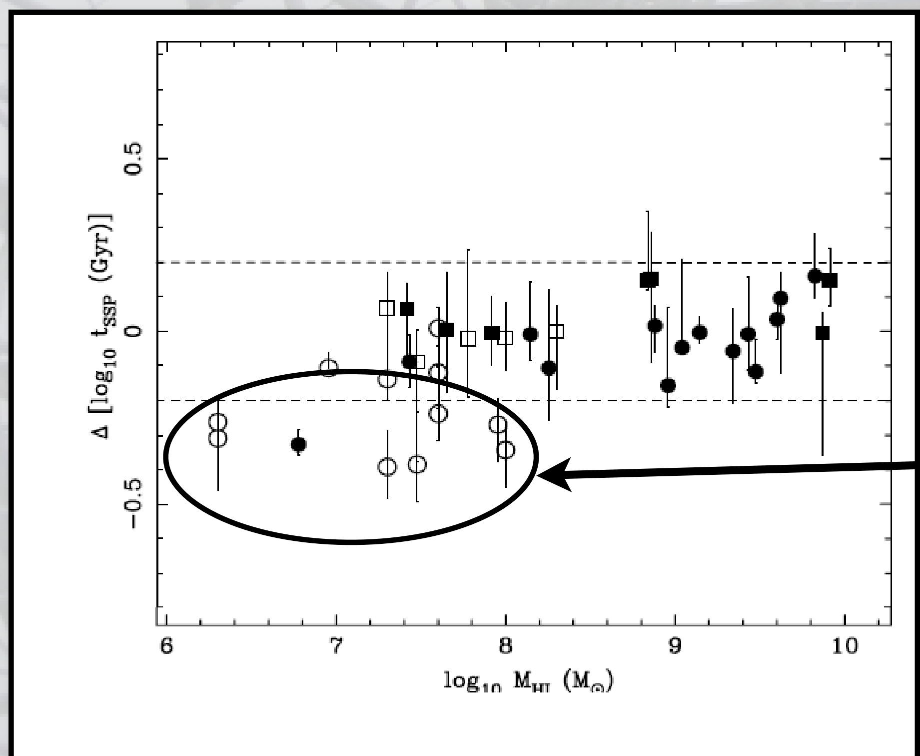

Galaxies with σ < 230 km s^{-1} and NO H I have younger centre (centrally rejuvenated)

No trend for H I detections and for more massive galaxies

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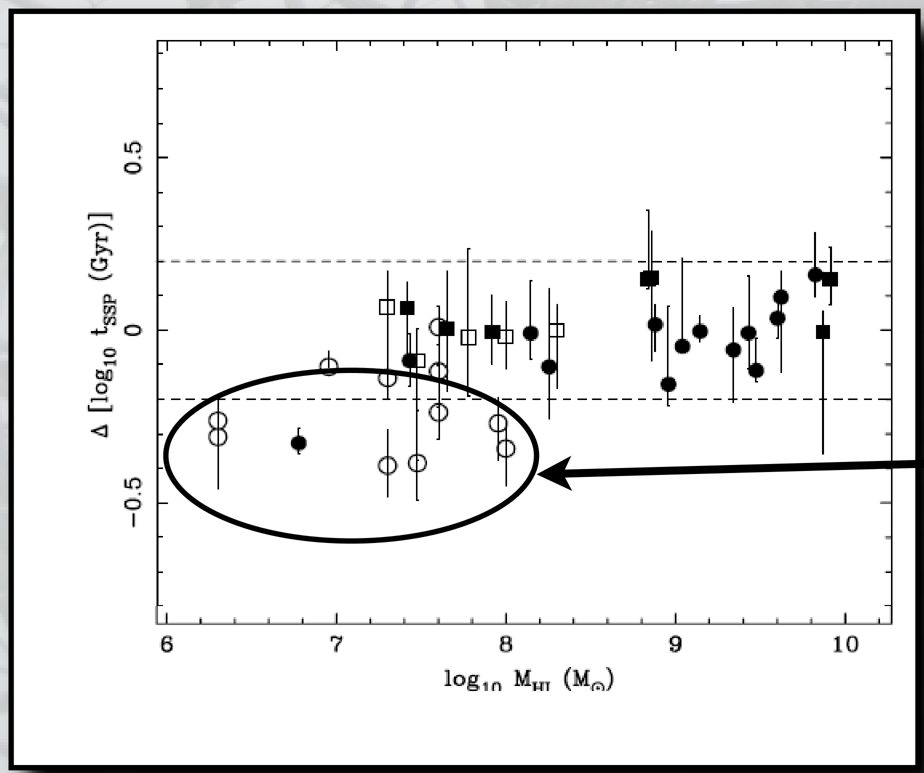

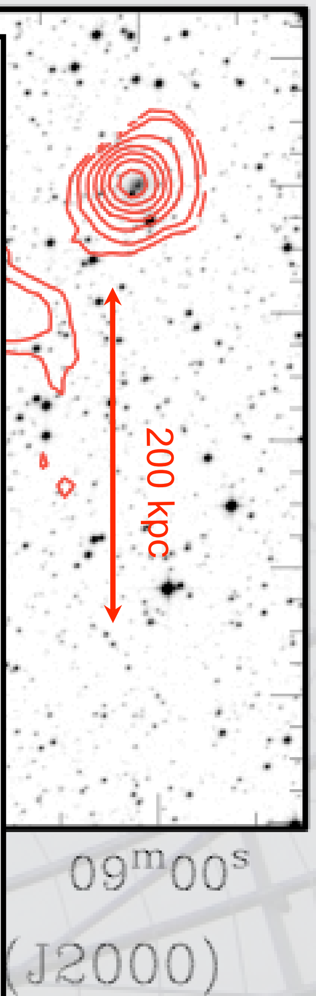

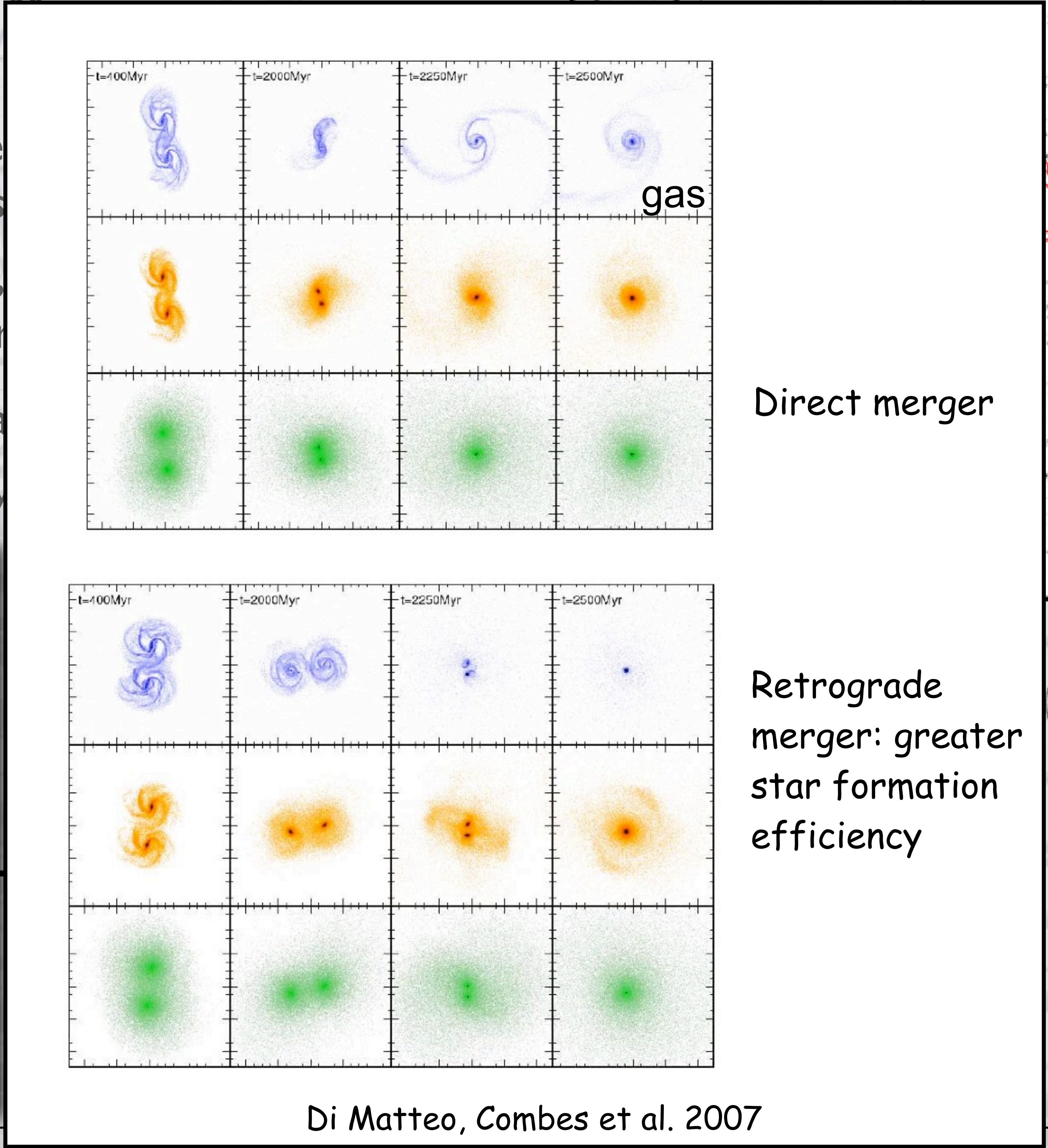

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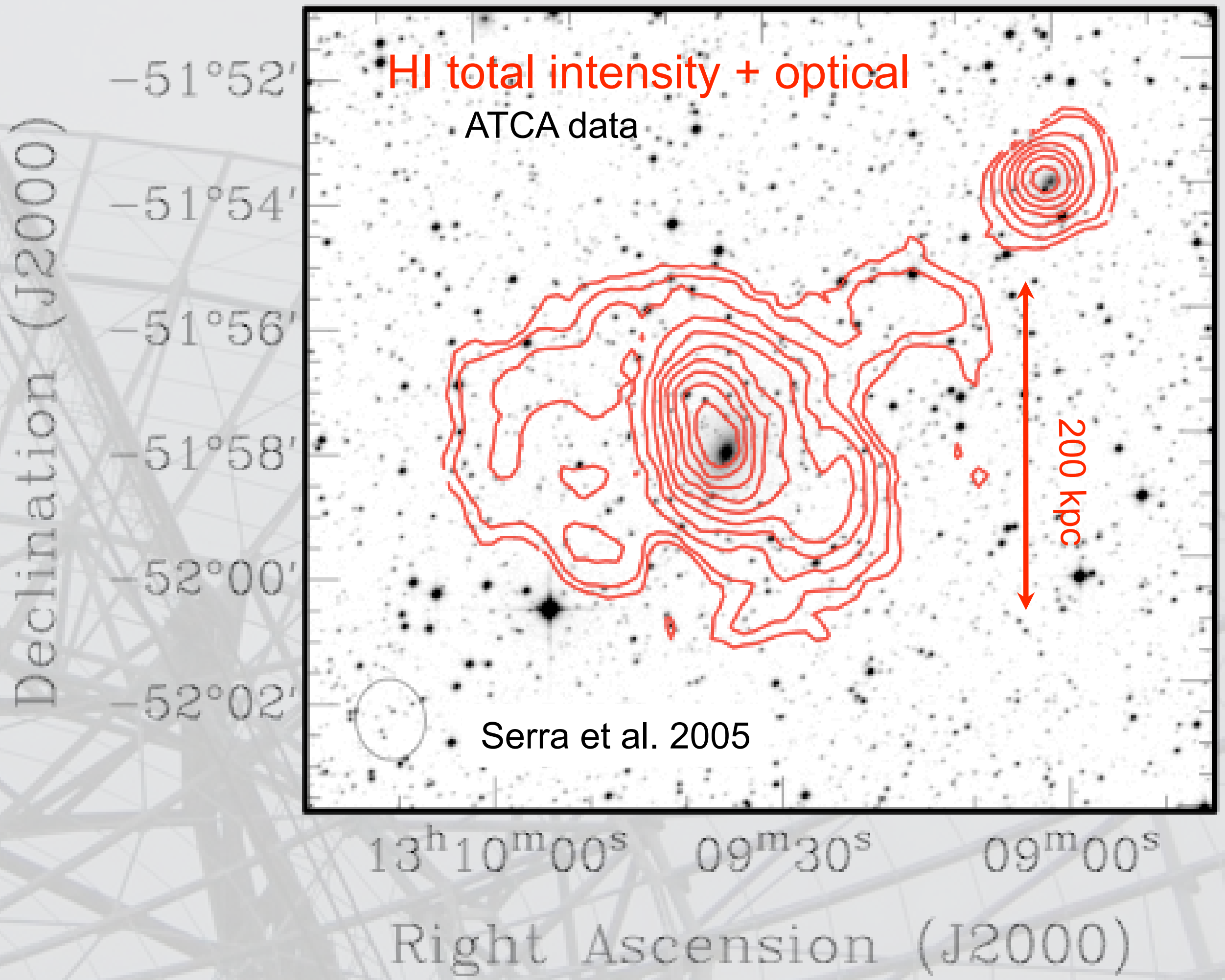

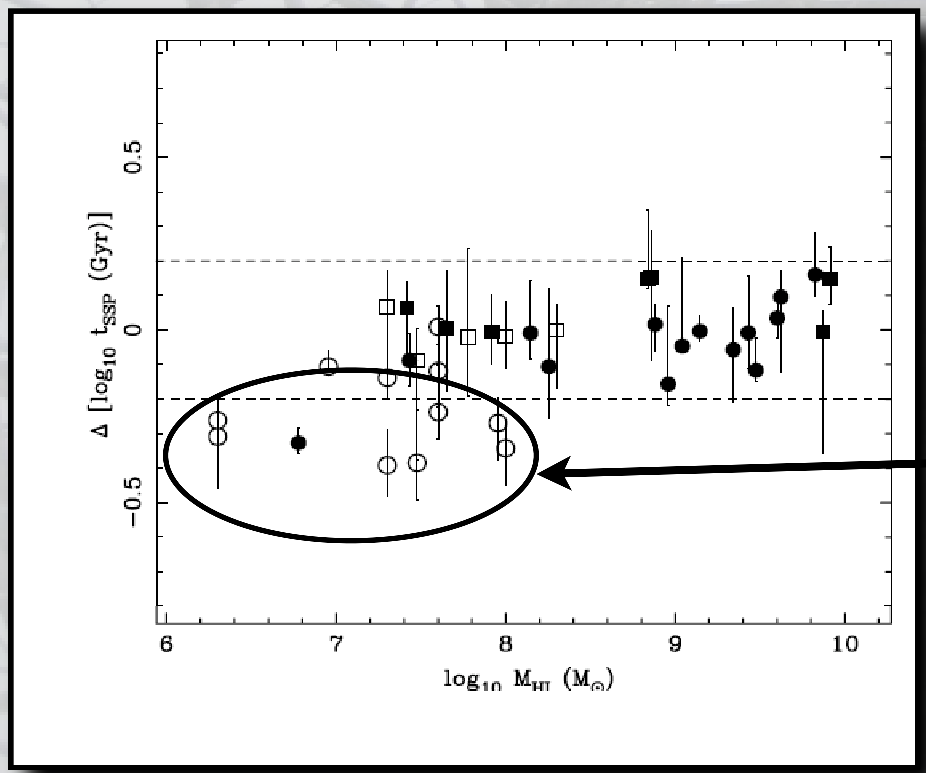

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Morganti R. , deZeeuw T. , Ooterloo T. , Mc Dermid R., Krajnovic D., Cappellari M., Kenn F., Weijmans A. Sarzi M. A&A (2006)

Going deeper....

Westerbork Synthesis Radio Telescope used to perform deep HI observations of nearby early-type *field* galaxies from the SAURON sample

↳integral-field spectrograph on the WHT: kinematics of ionised gas and stars

A large range of HI masses and morphologies
(HI mass limit few x 10^6 $M_\odot$)

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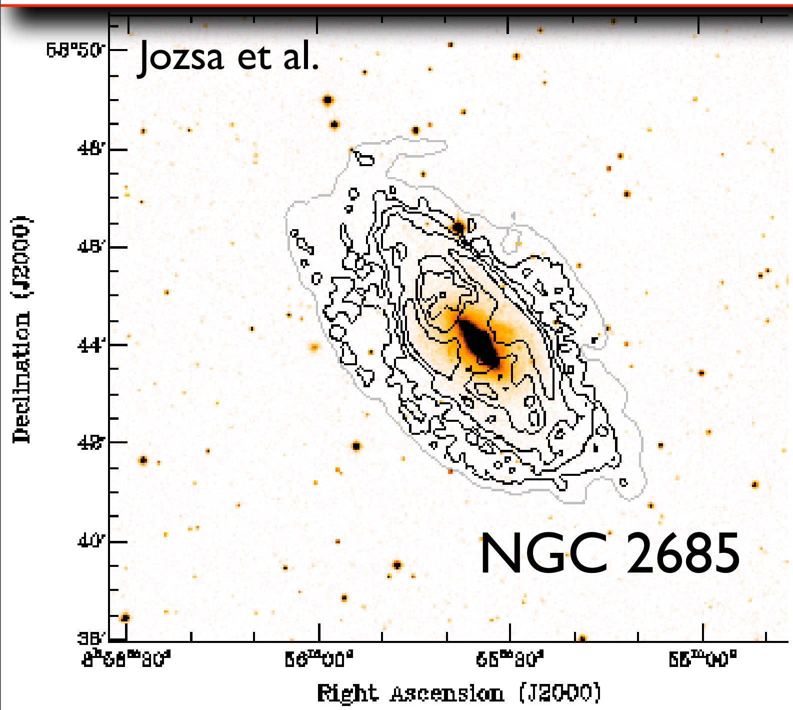
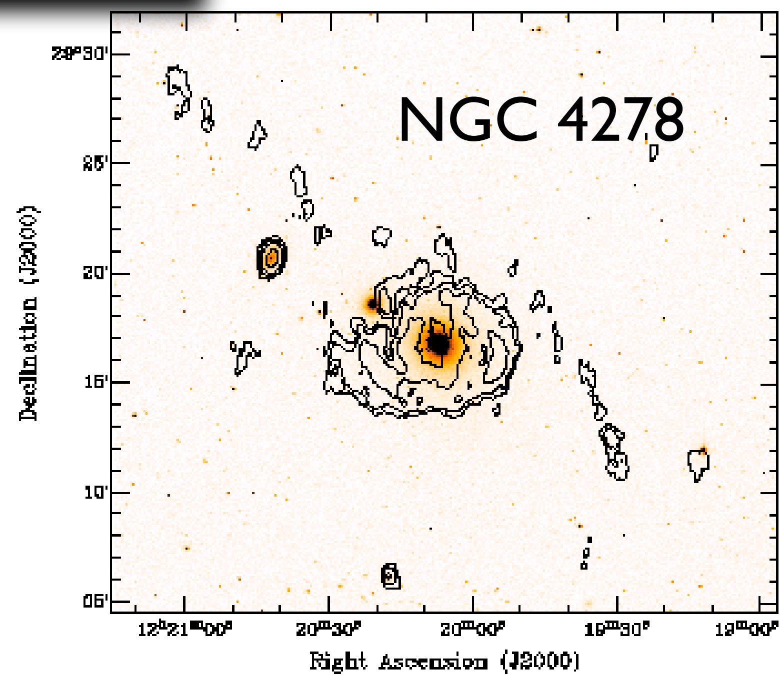
Surprising: high detection rate (~60-65%) of galaxies with HI for field galaxies !

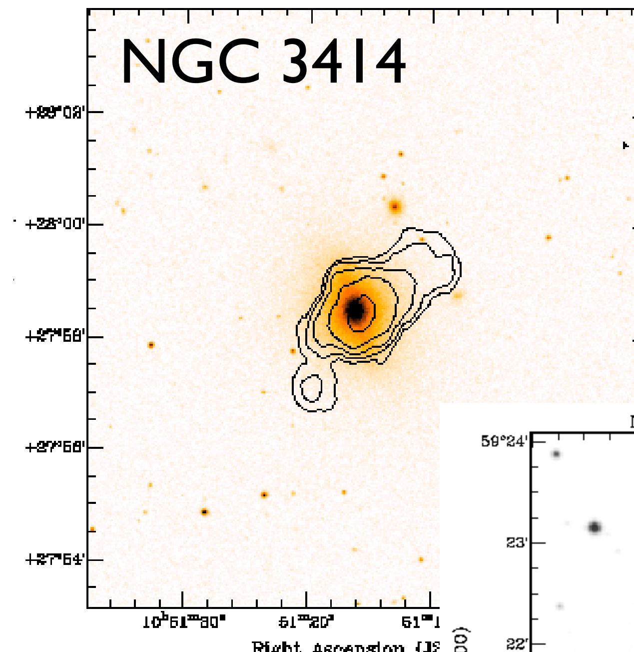
HI in early-type galaxies: how often, how much (2)

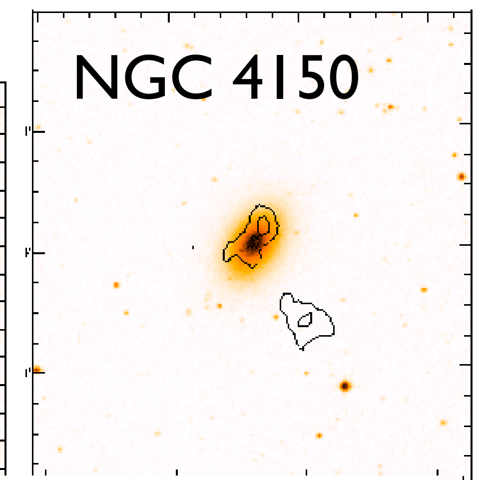
Morganti R. , deZeeuw T. , Ooterloo T. et al. (2006)

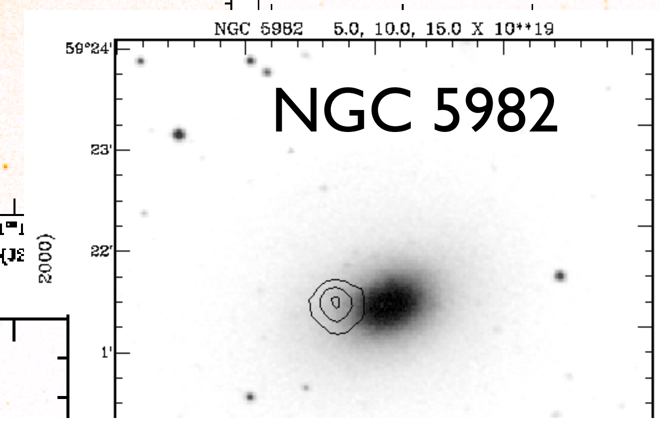
Regularly rotating HI structures



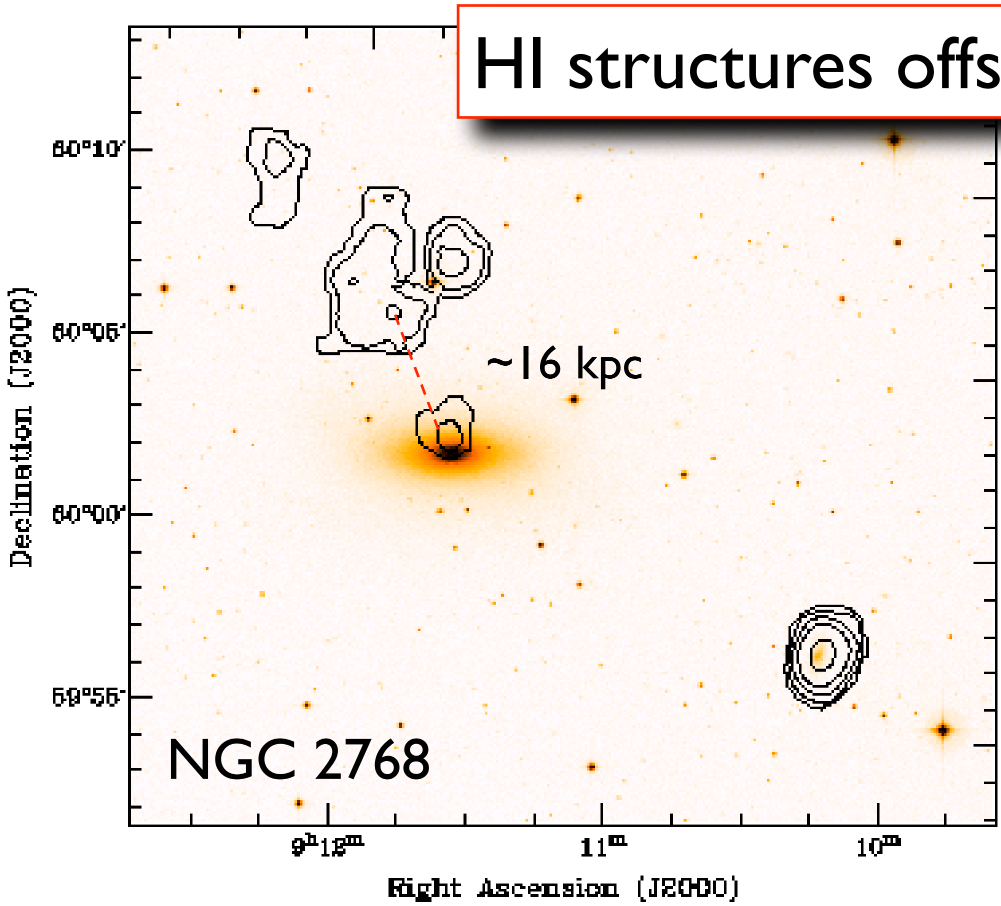


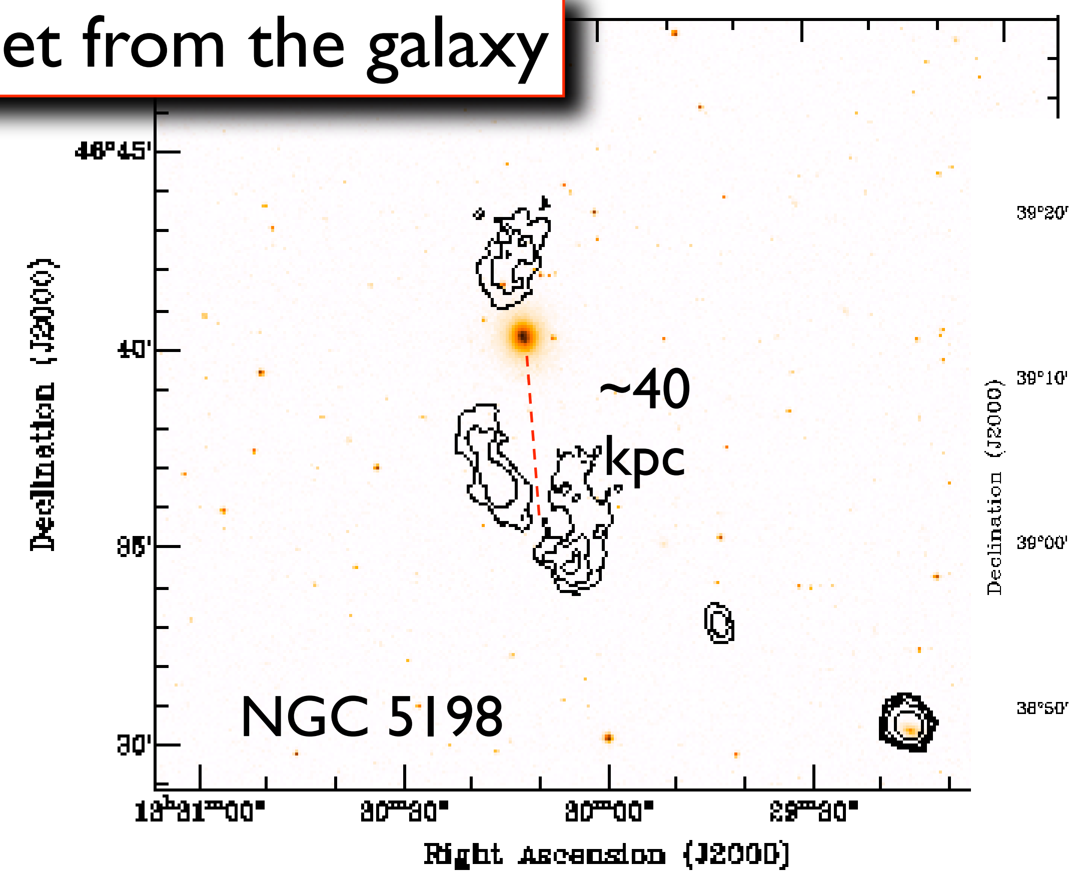


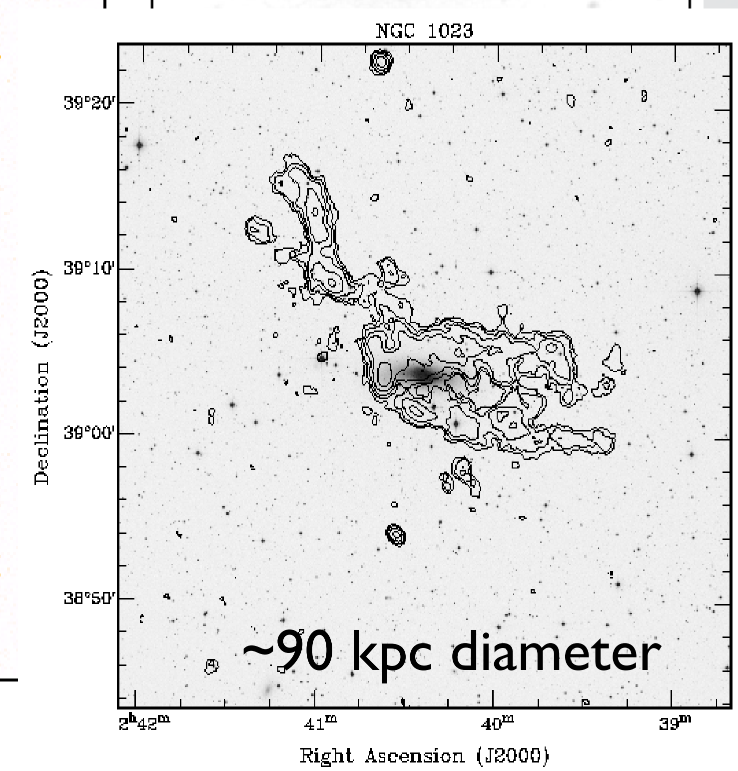




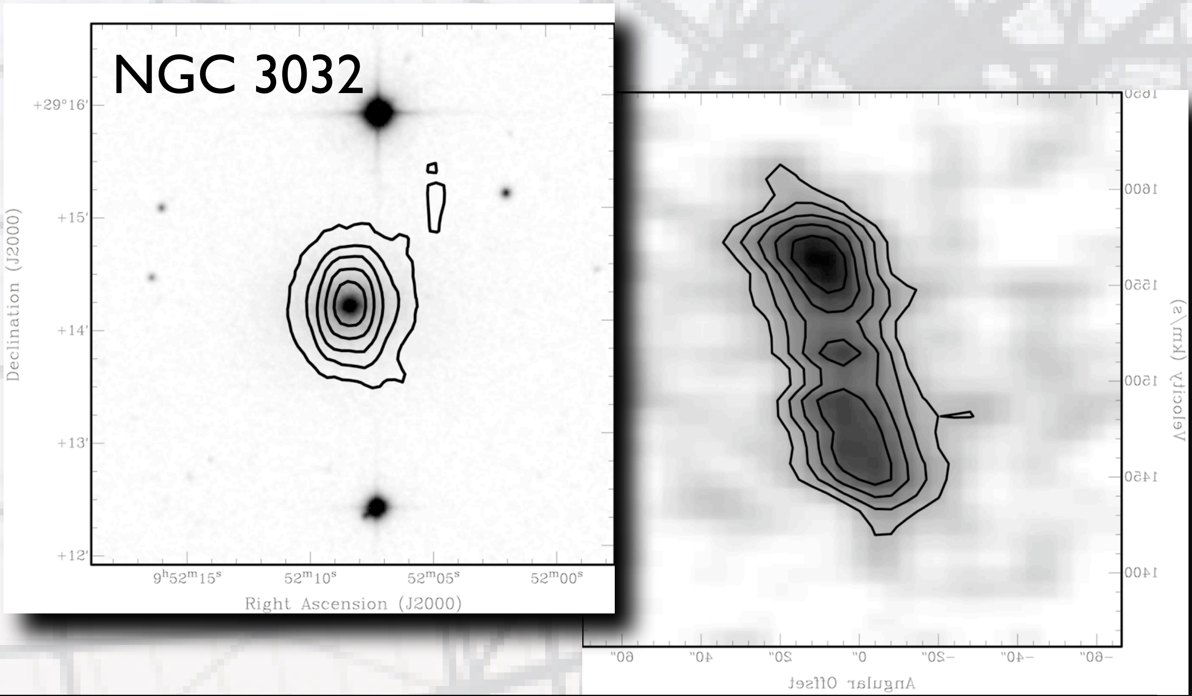
HI structures offset from the galaxy



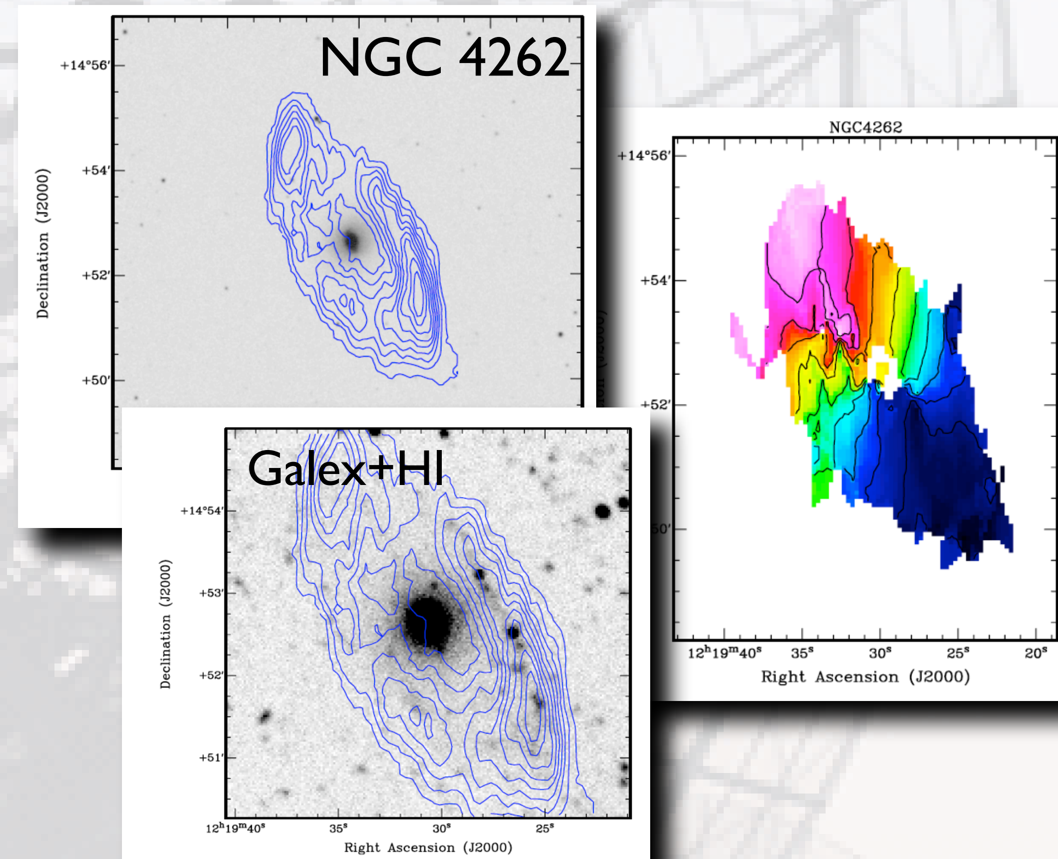




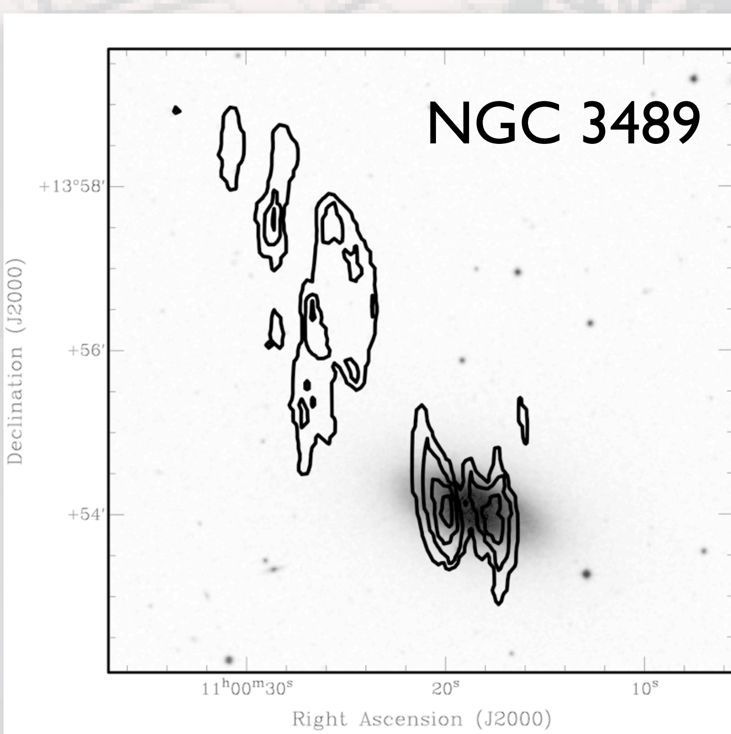
Recent extension of the WSRT observations of Sauron galaxies - also dense environment galaxies



Small, regularly rotating HI,
is the same structure as seen in CO and ionised gas
(rotating opposite to stars).
Ratio HI/H_2 ~1:10



S0 with large HI ring (20 kpc diameter).
5 x 10^8 $M_\odot$
Strong bar, non-circular orbits
NUV image from GALEX indicates knots of star formation
This is the only detection (of our sample) so far in dense environment



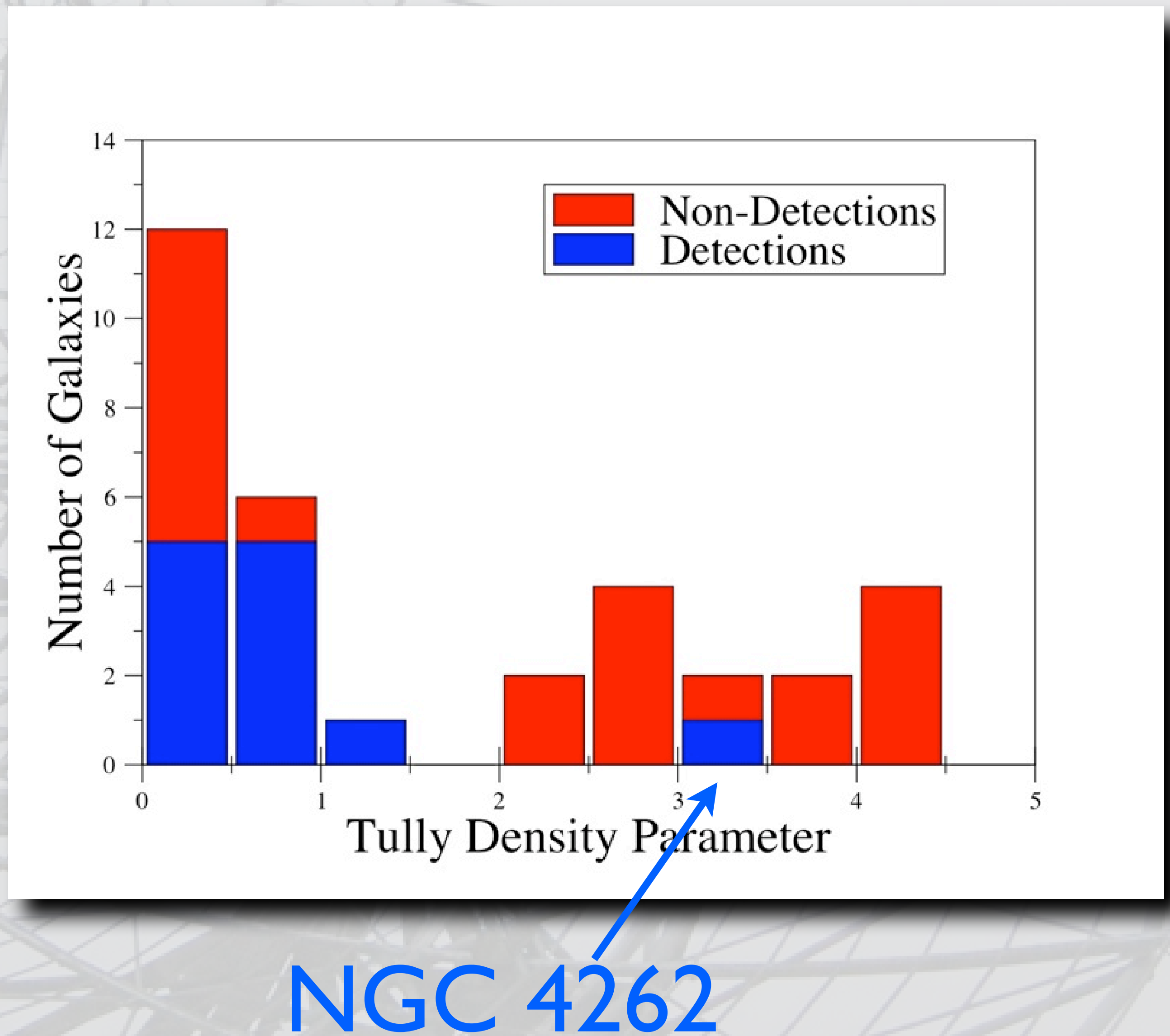
Central HI small disk(?)
+ low-column density tail
Is this how disks form?
CO detected
(Young, Combes, Bureau 2007)

Oosterloo T., Morganti R., Crocker A., Manthey E., + SAURON Team in prep.

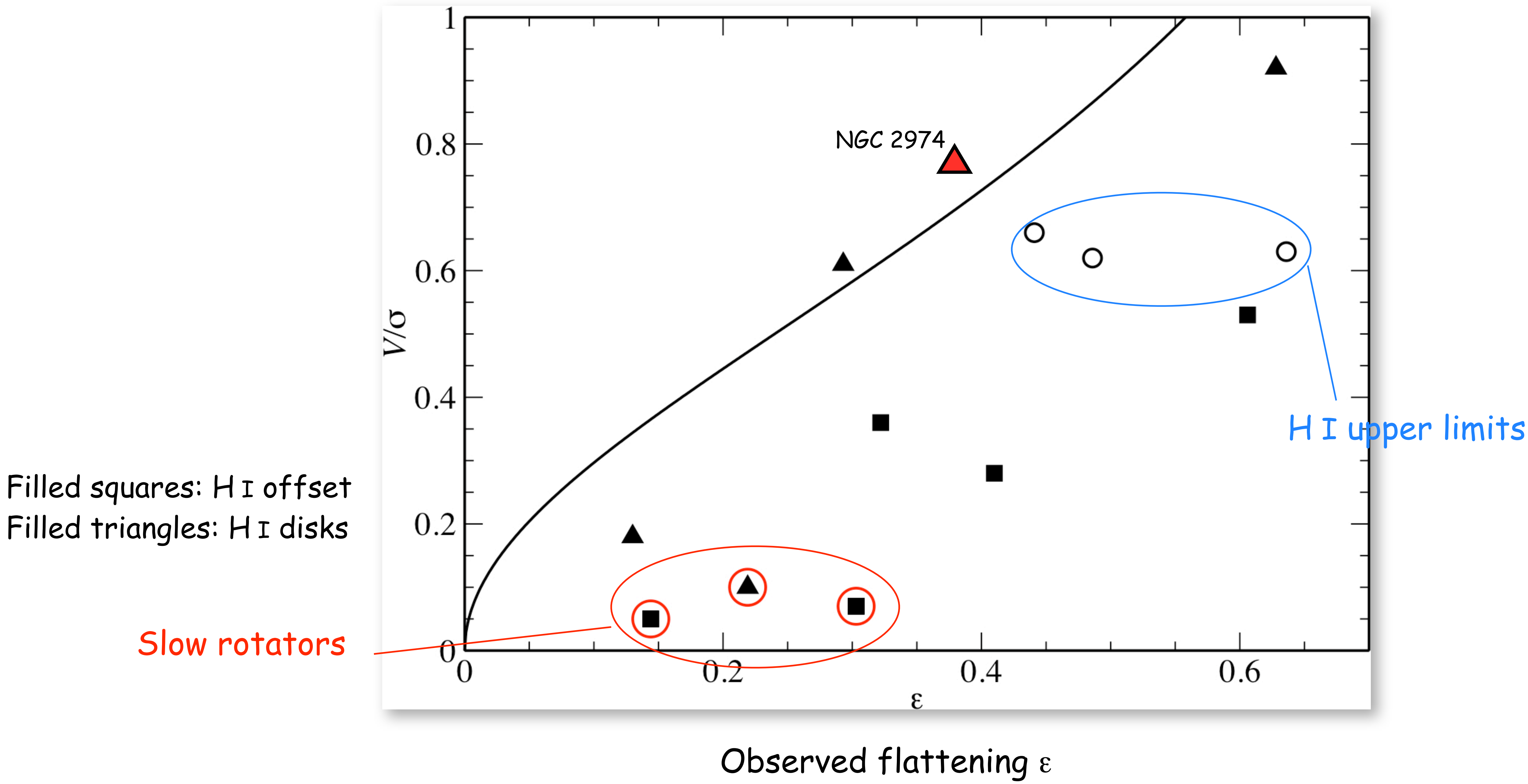
Relations between HI and other properties

Environment

- We used the Tully density parameter to quantify the environment
- Detections are in low-density environment
- Only one galaxy (NGC4262) in dense environment - although there are other cases known: M86, M49,...



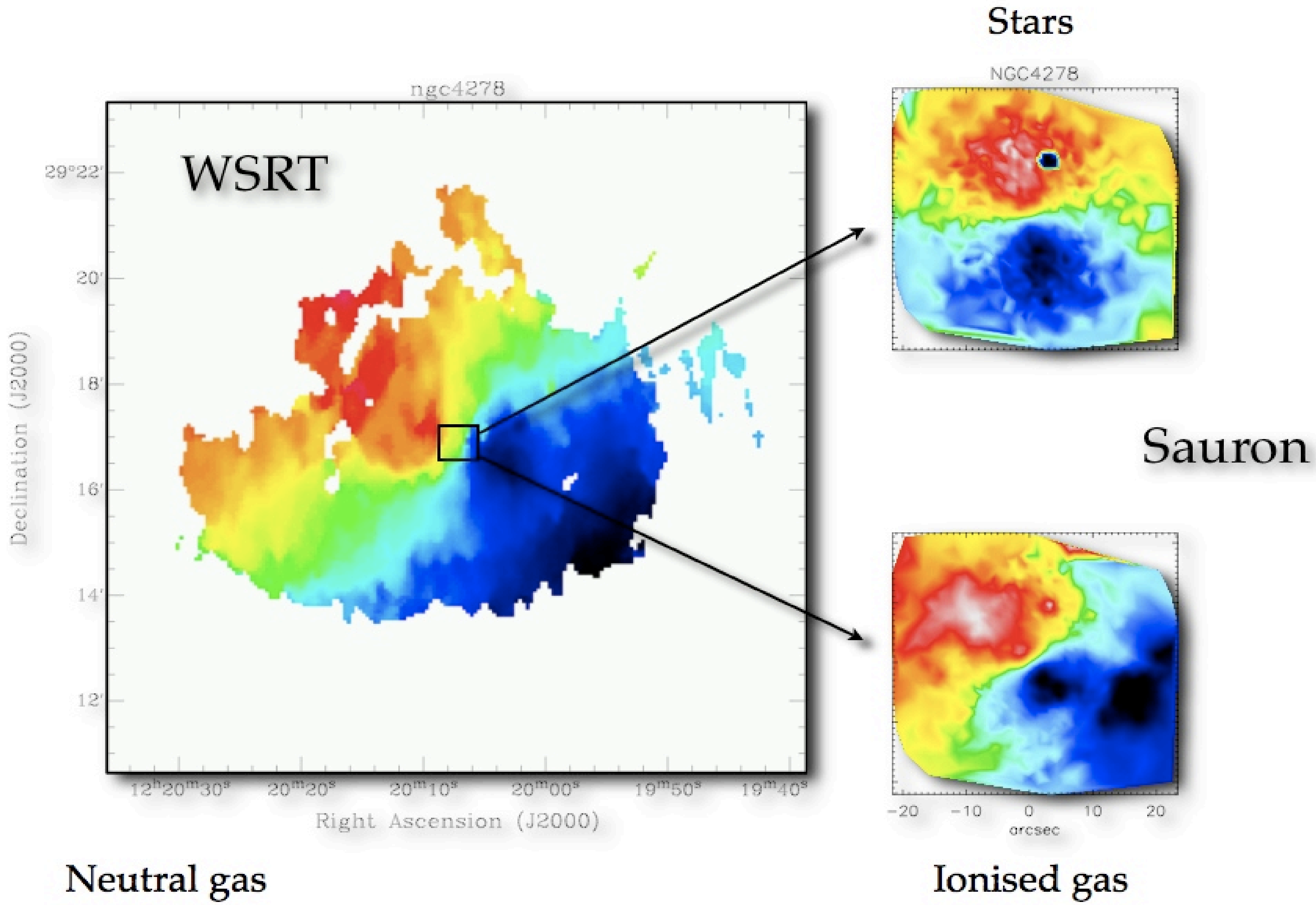
Stellar dynamics



- HI and dynamics ⇒ both E and S0 have HI

Relation with ionised gas

Example of kinematics of gas (neutral and ionised) and stars: NGC 4278

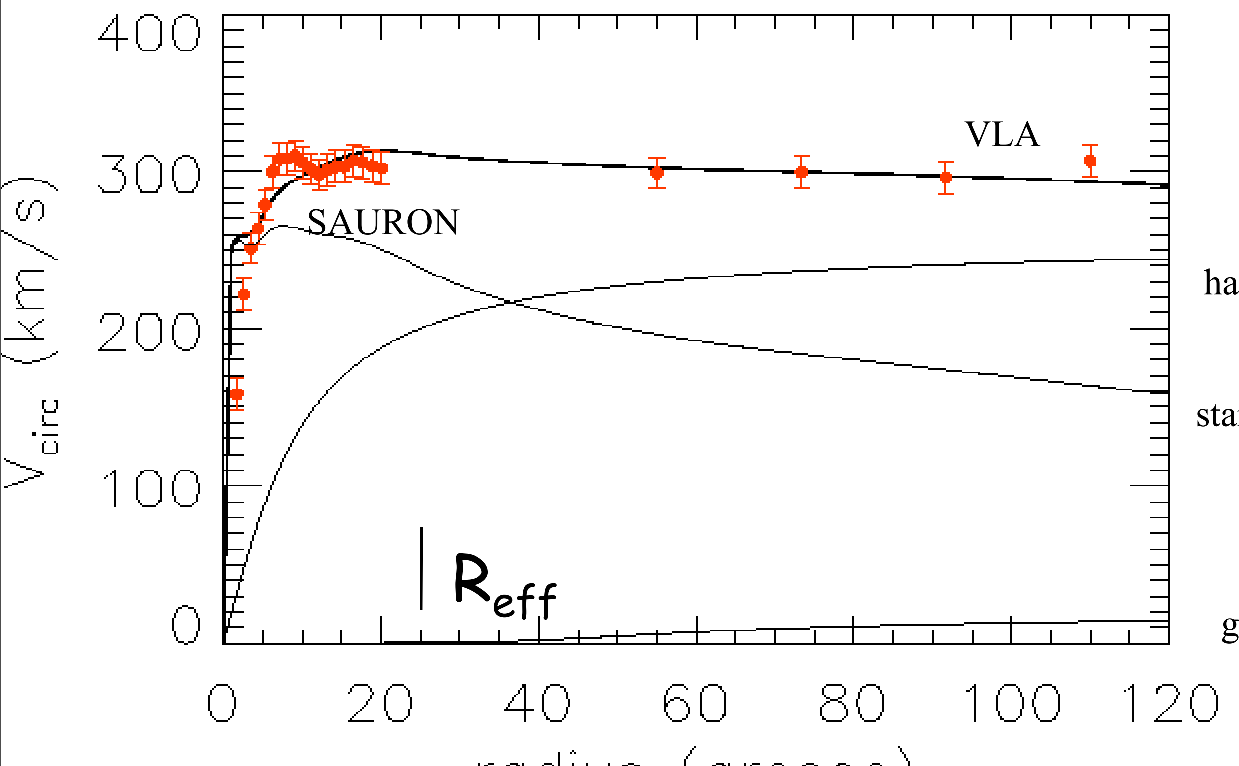


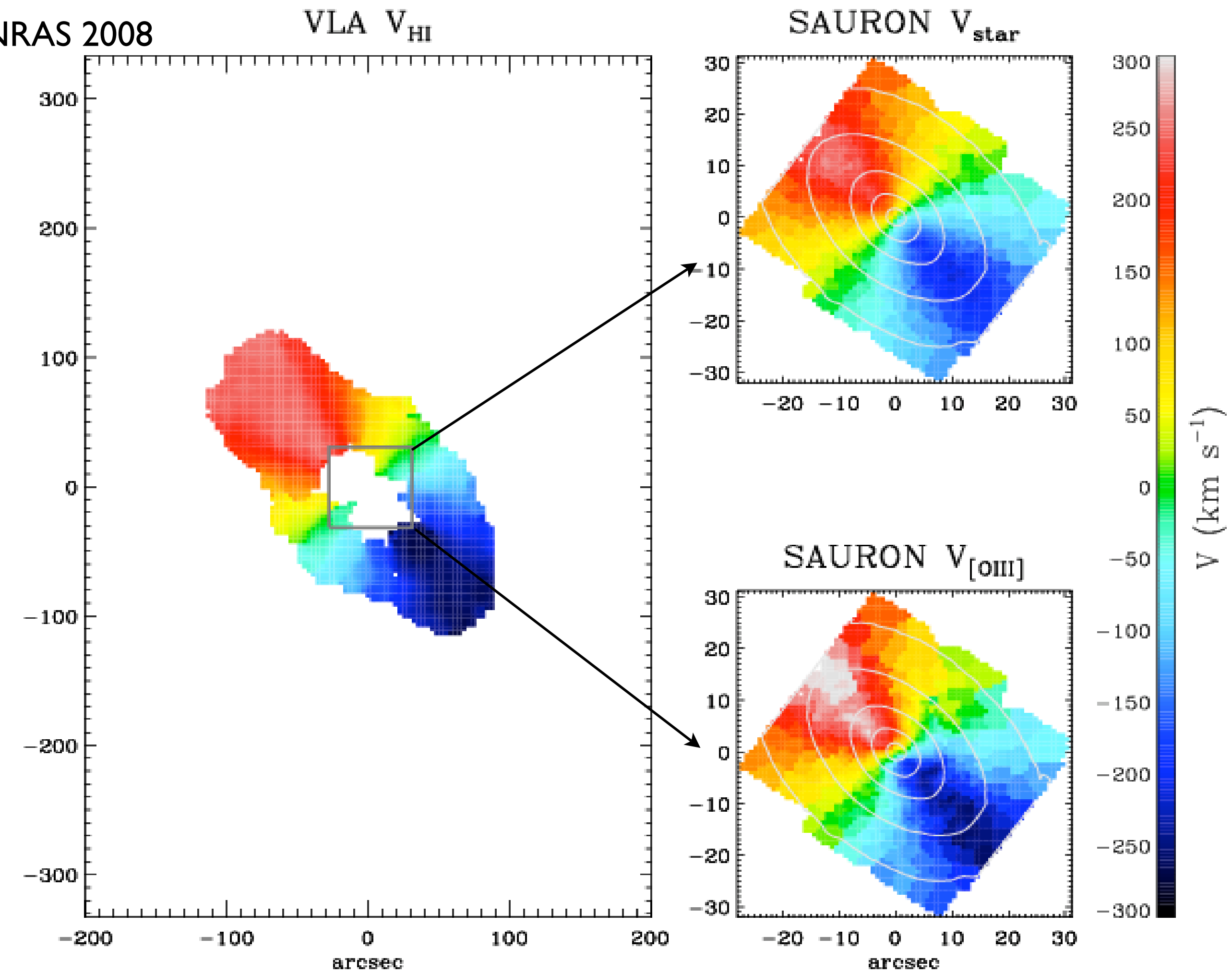
⟹ Galaxies with regular HI disks also have extended, kinematically regular structures of ionised gas

Example of what we can do with these data: NGC 2974

Weijmans A.-M., Krajnovic D., van der Ven G., Oosterloo T., Morganti R., de Zeeuw T. MNRAS 2008

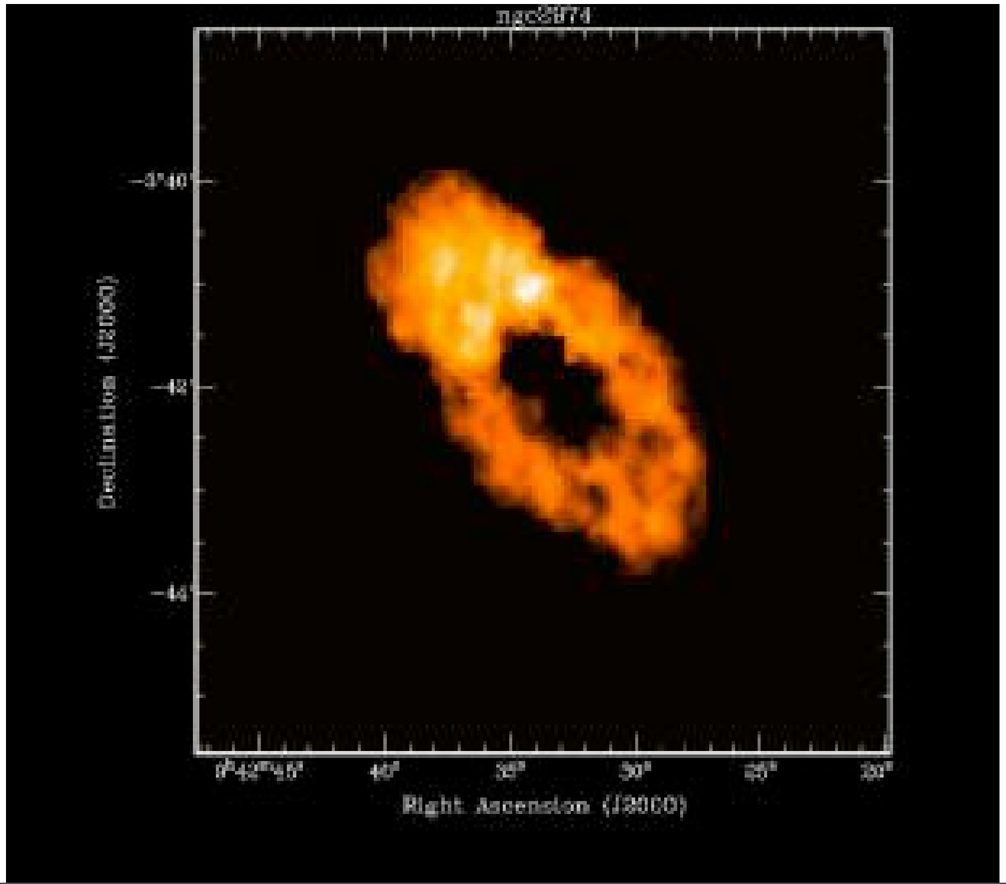
Sauron + VLA





Mass model combining HI rotation curve with the central kinematics of the ionised gas.

Increase M/L ⇒ dark matter (M/L from from 4.3 to 8.5 $M_\odot/L_{\odot,I}$ between 1 and 5 R_e)



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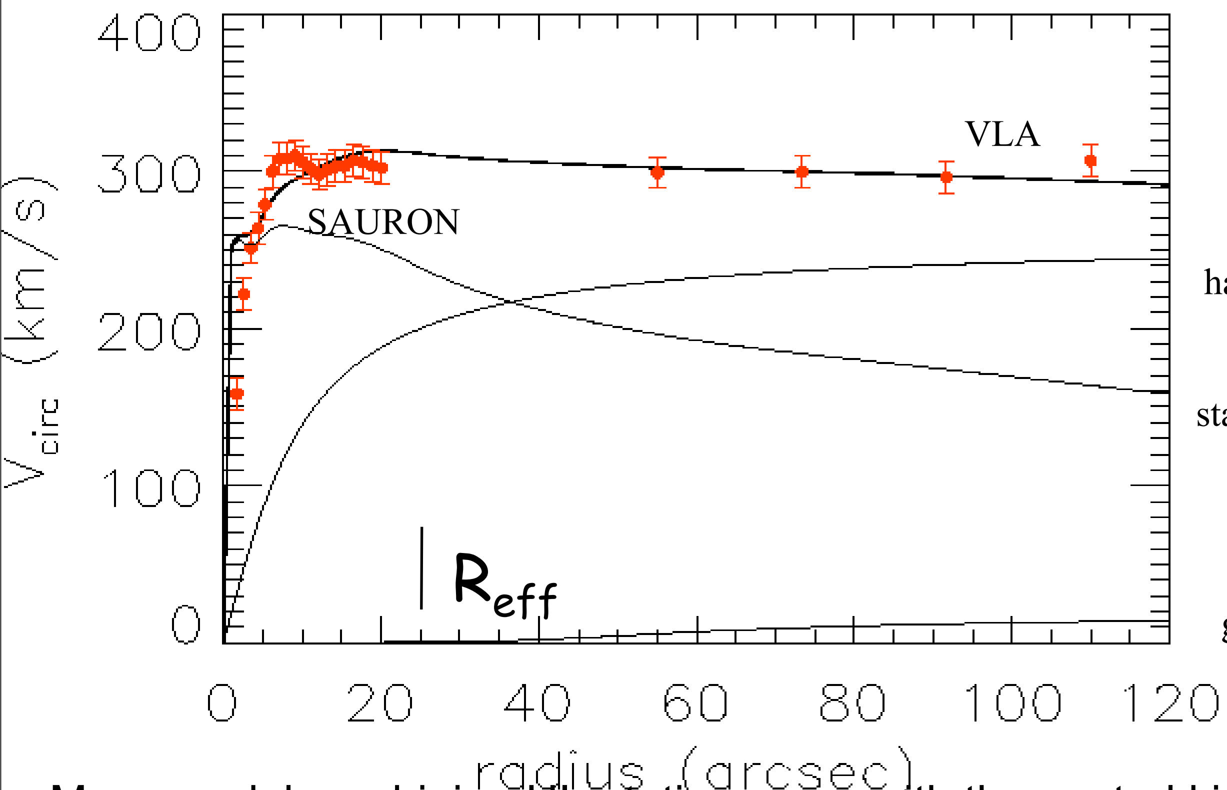

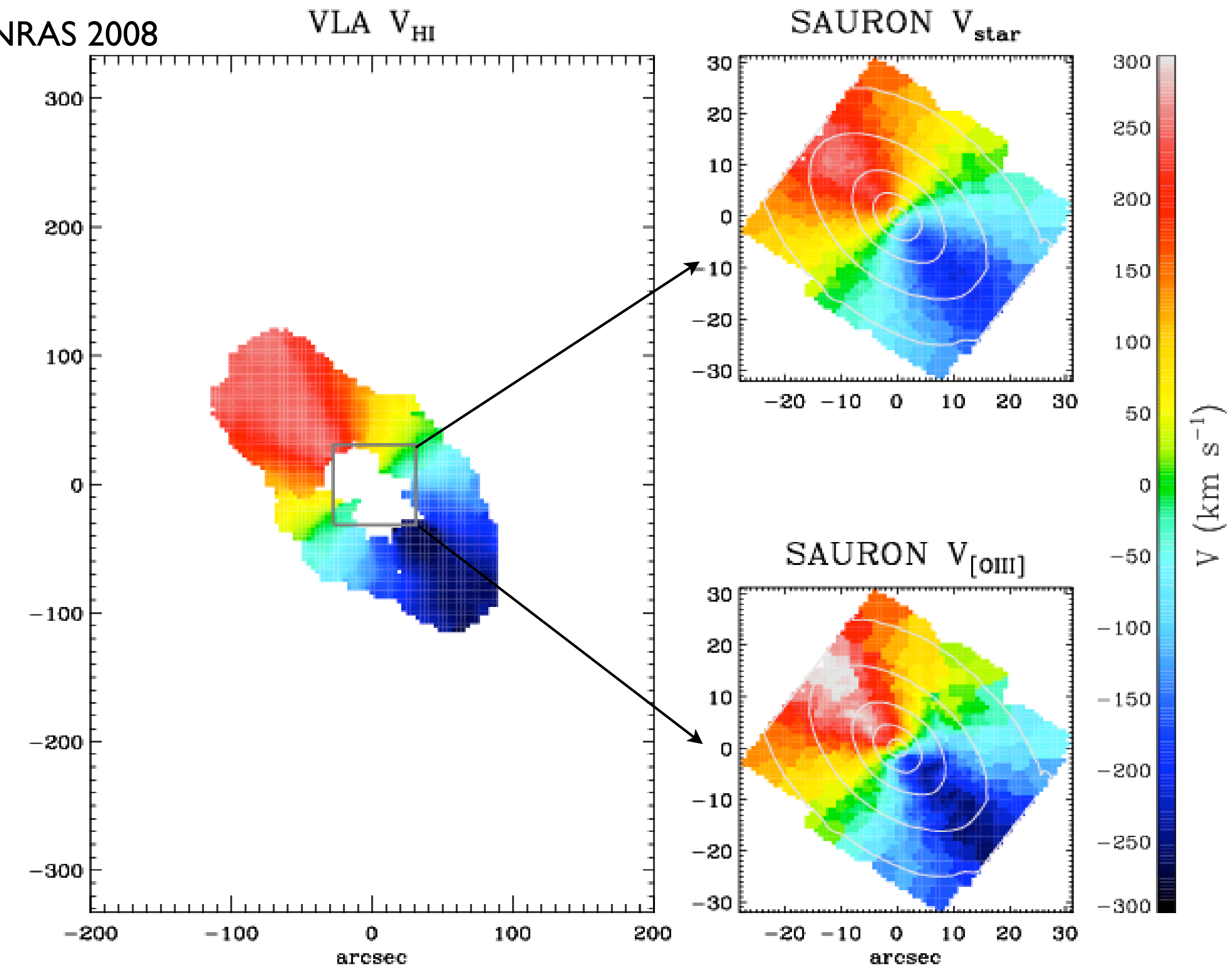

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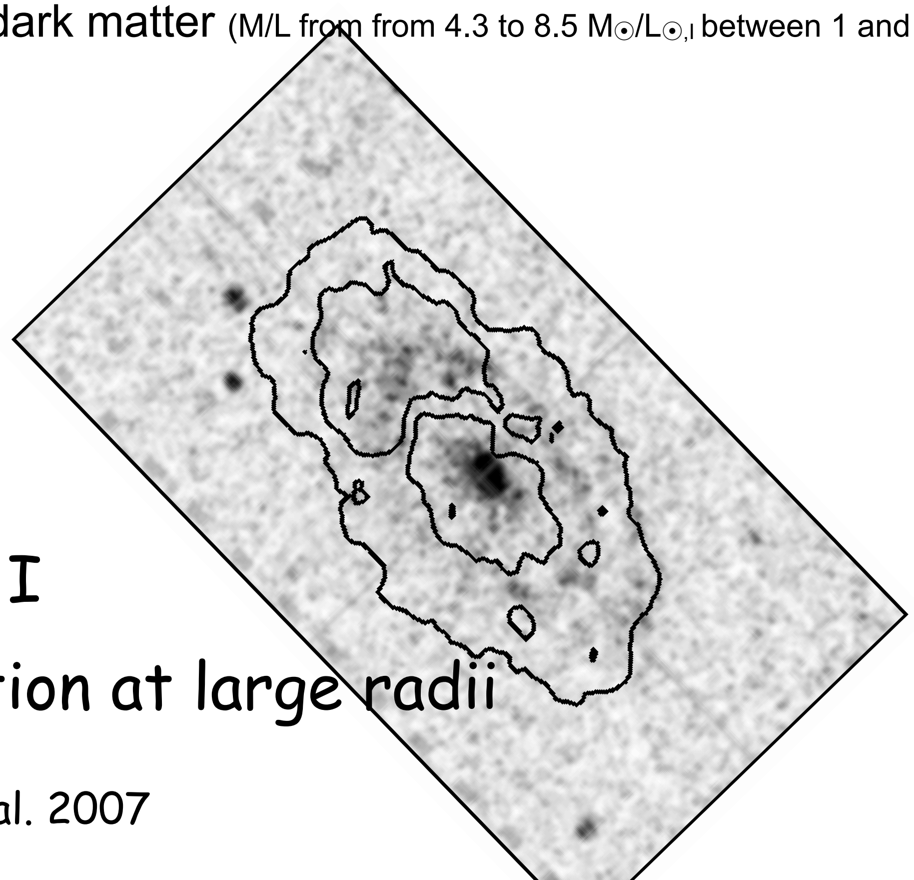
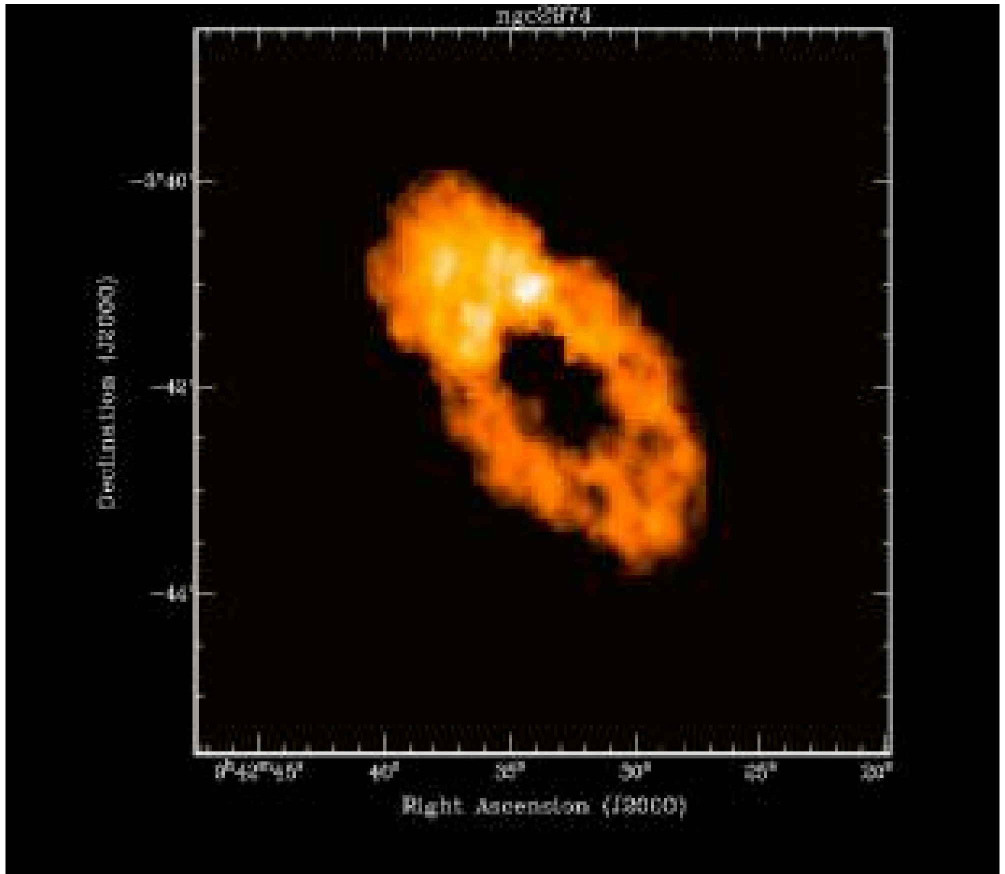


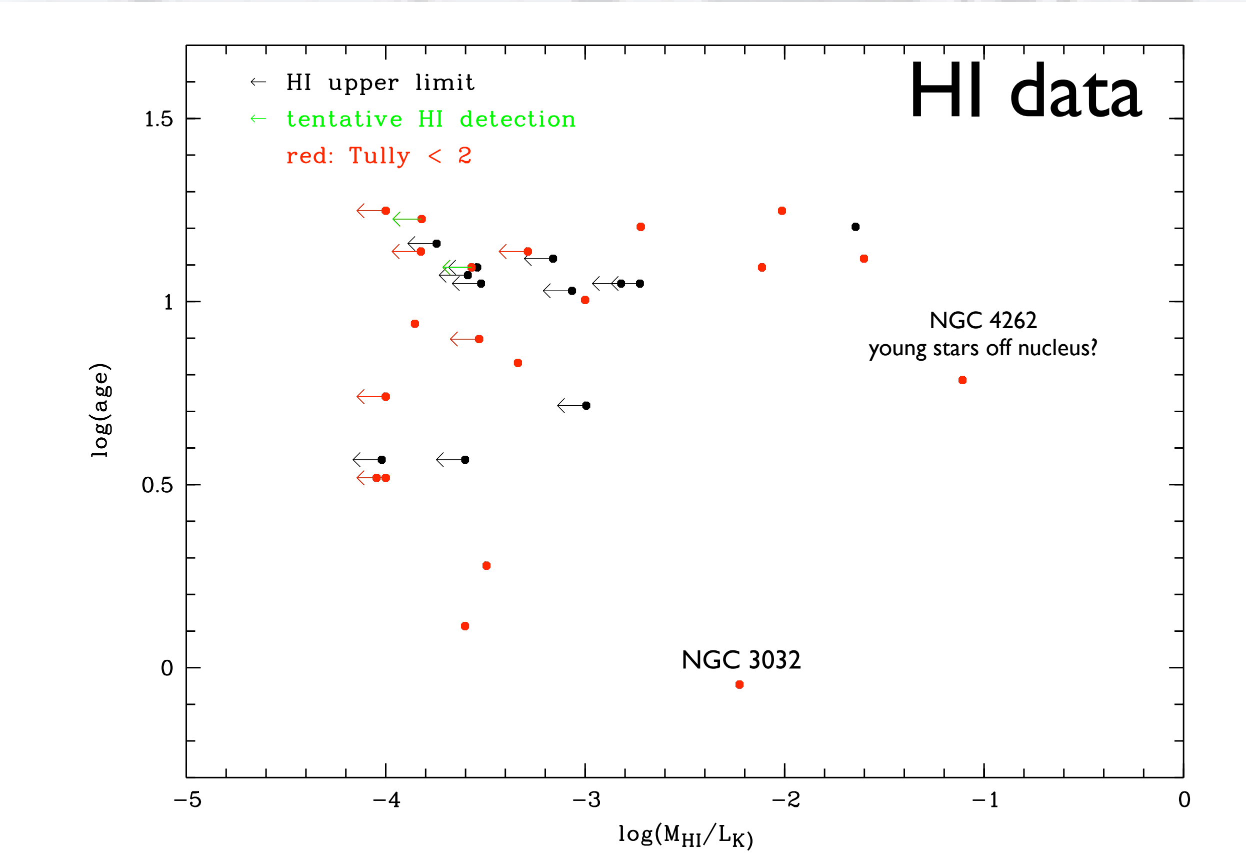


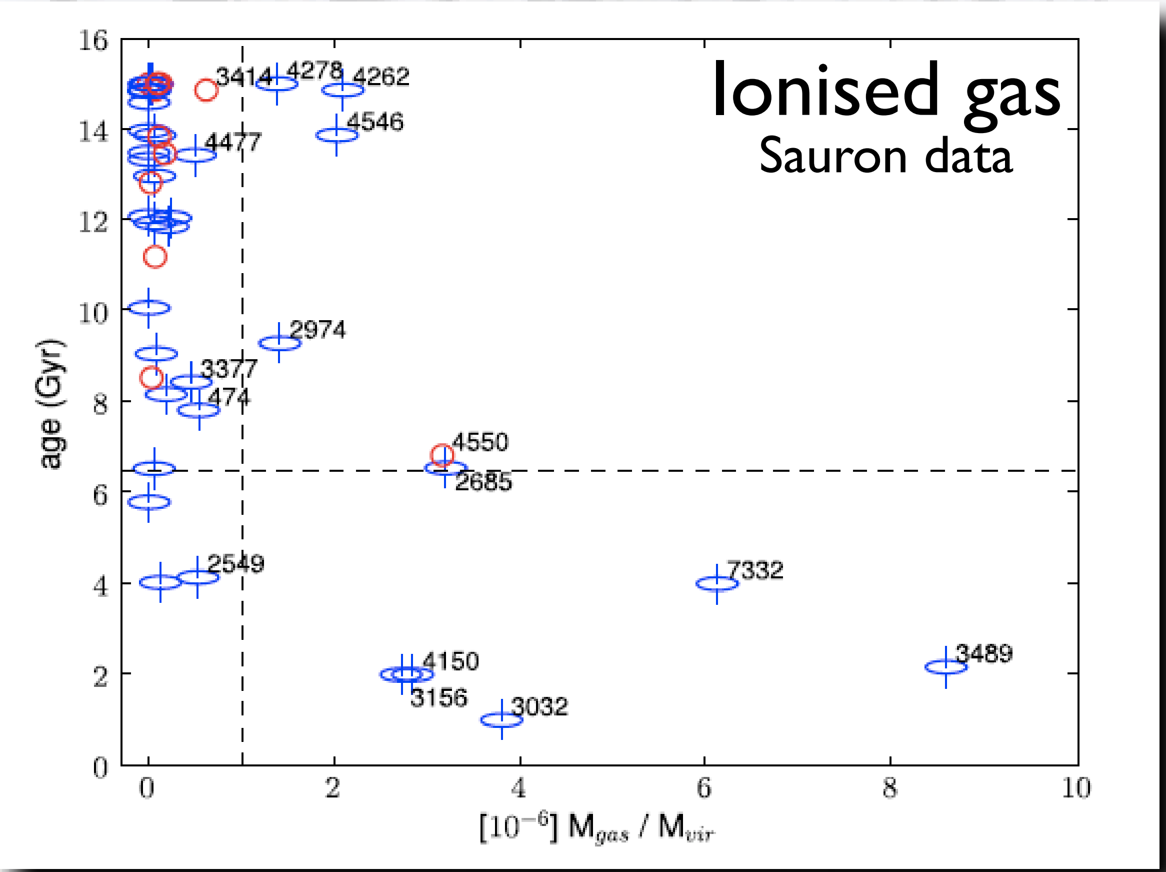
Galex & H I

Star formation at large radii

Jeong, Bureau et al. 2007

Stellar population and HI





Values of the stellar ages from Harald Kuntschner

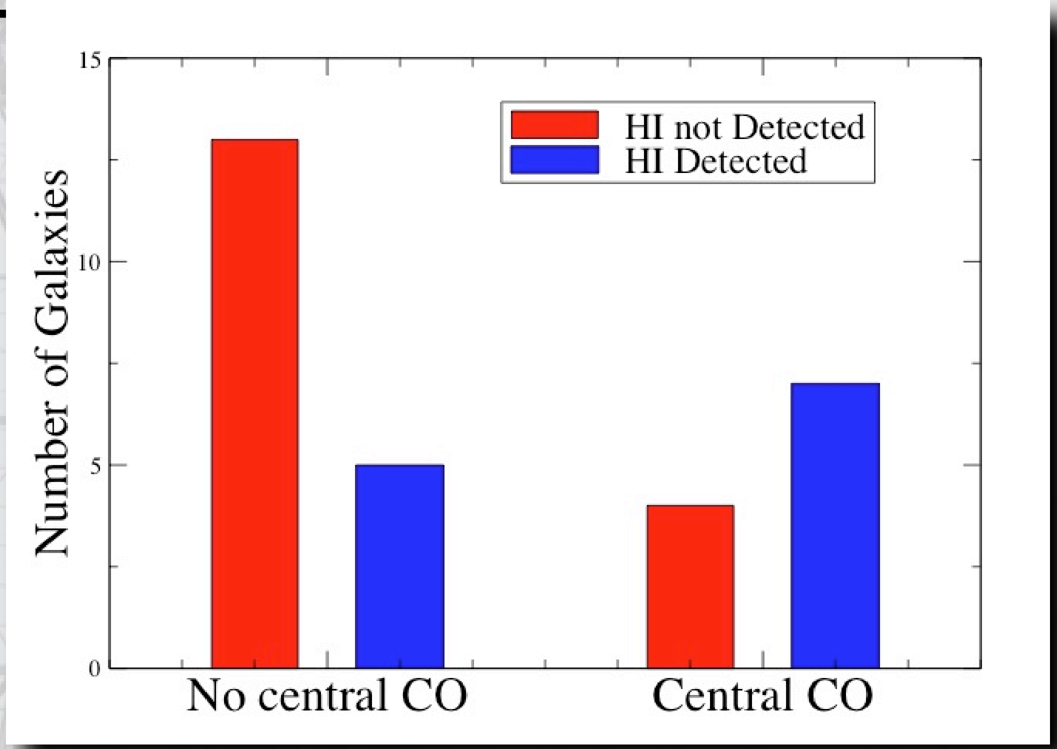
No clear correlation - confusing results with the ionised gas!

$\Longrightarrow$ Many systems acquire gas but only in some this gas manages to form stars and gets consumed. In other galaxies the gas can stay around for very long time at large radii "doing nothing".

$\Longrightarrow$ radial gradients in stellar populations young at large r

Molecular gas and HI

- CO data come from IRAm 30m observations (Combes, Young, Bureau 2007)
- Not a terribly strong correlation, but: **galaxies with CO are more likely to have HI**
- **But beam size for CO is small**



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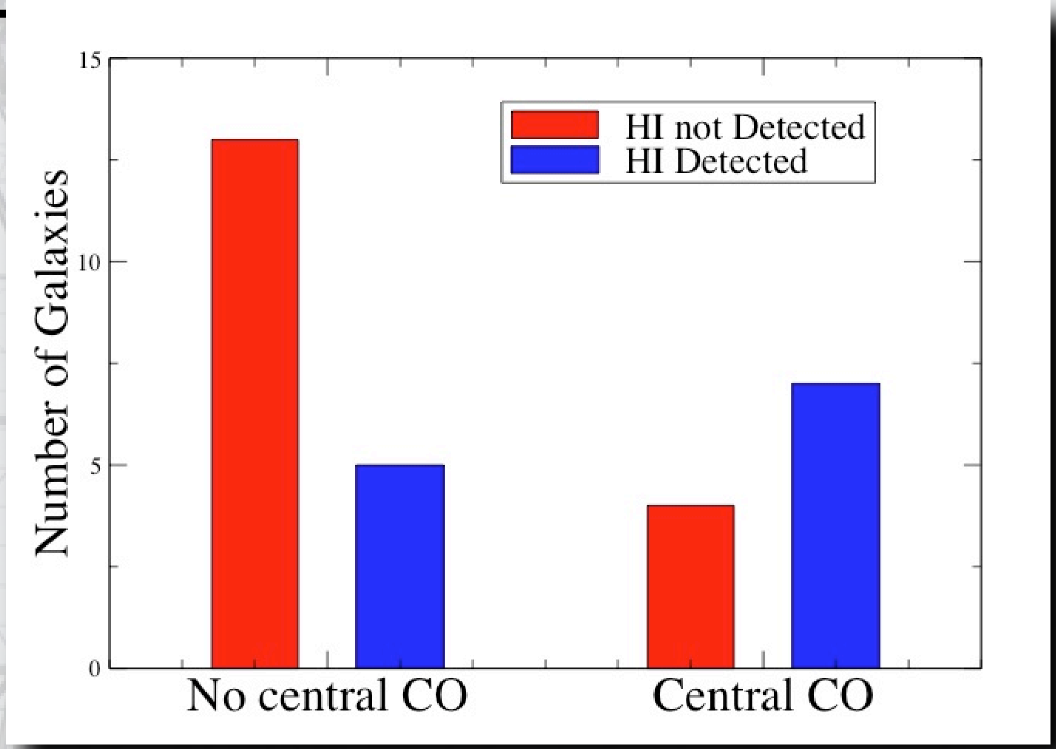
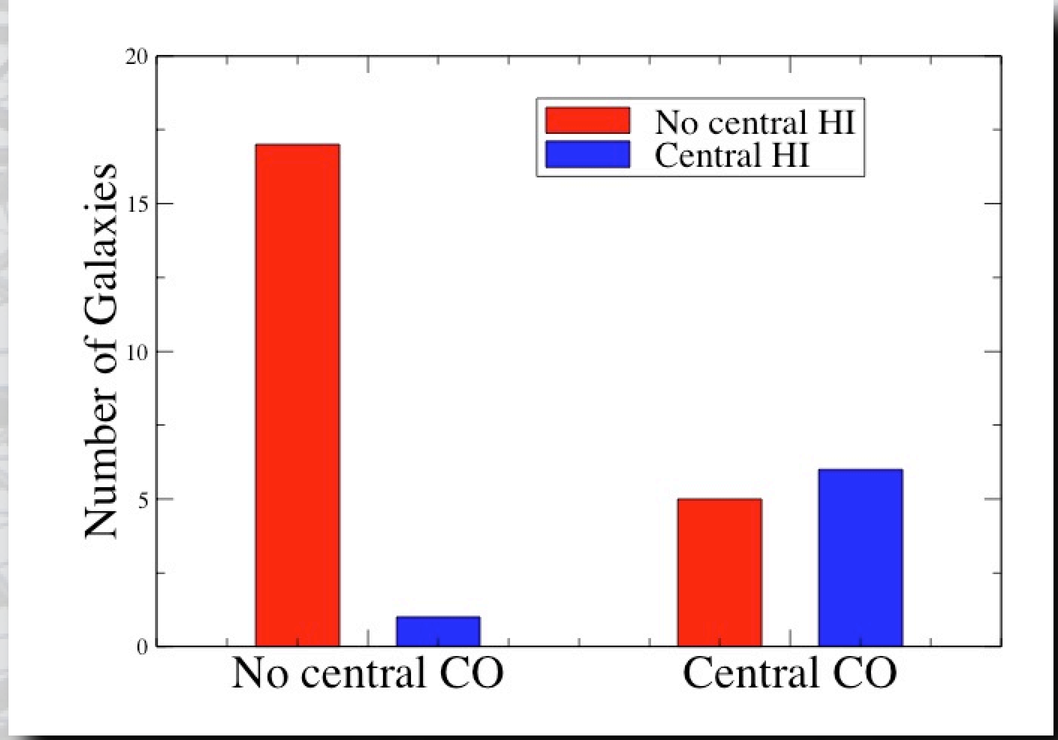


- Compare only those with central HI to the CO detections
- All (except one) galaxies with central HI also have central CO
- **But there is also a set of galaxies with central CO and no evidence of central HI: why?**
- **Note N3032 with much more H_2 than HI.**



Summary of this part!

1. HI a *common characteristics* of *field* early-type galaxies if deep enough observations are available

2. HI detected in both E and S0 - a large range of HI masses and morphologies

3. No preference for peculiar galaxies

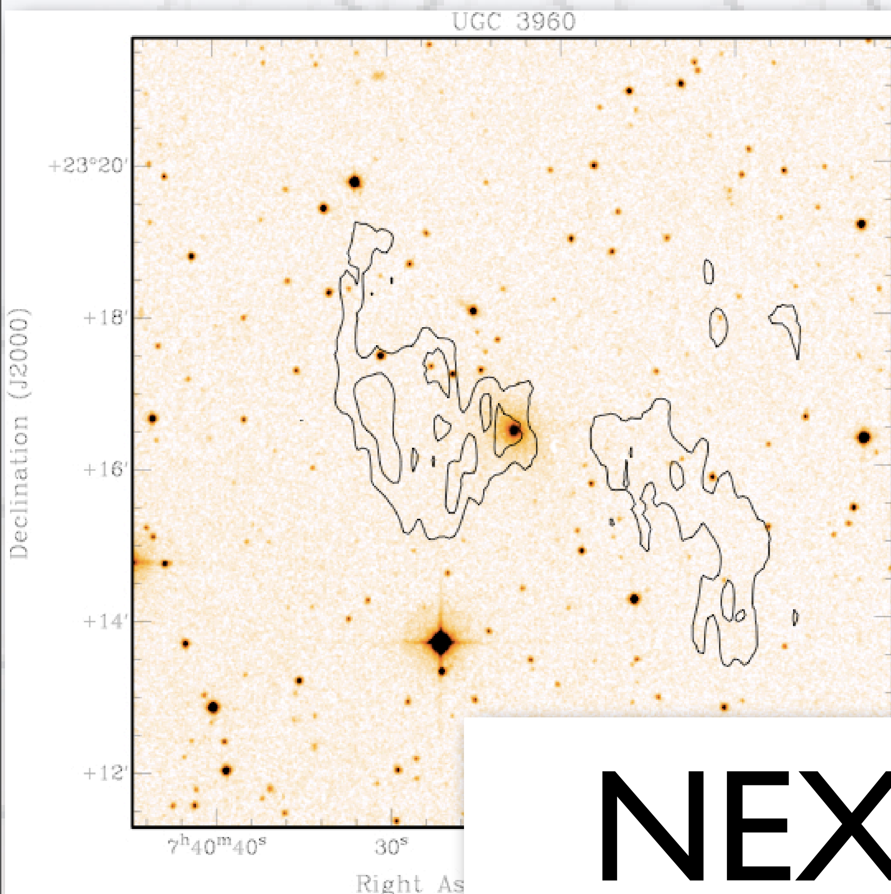
4. Origin of the HI mainly external: from major mergers to - perhaps - IGM accretion?

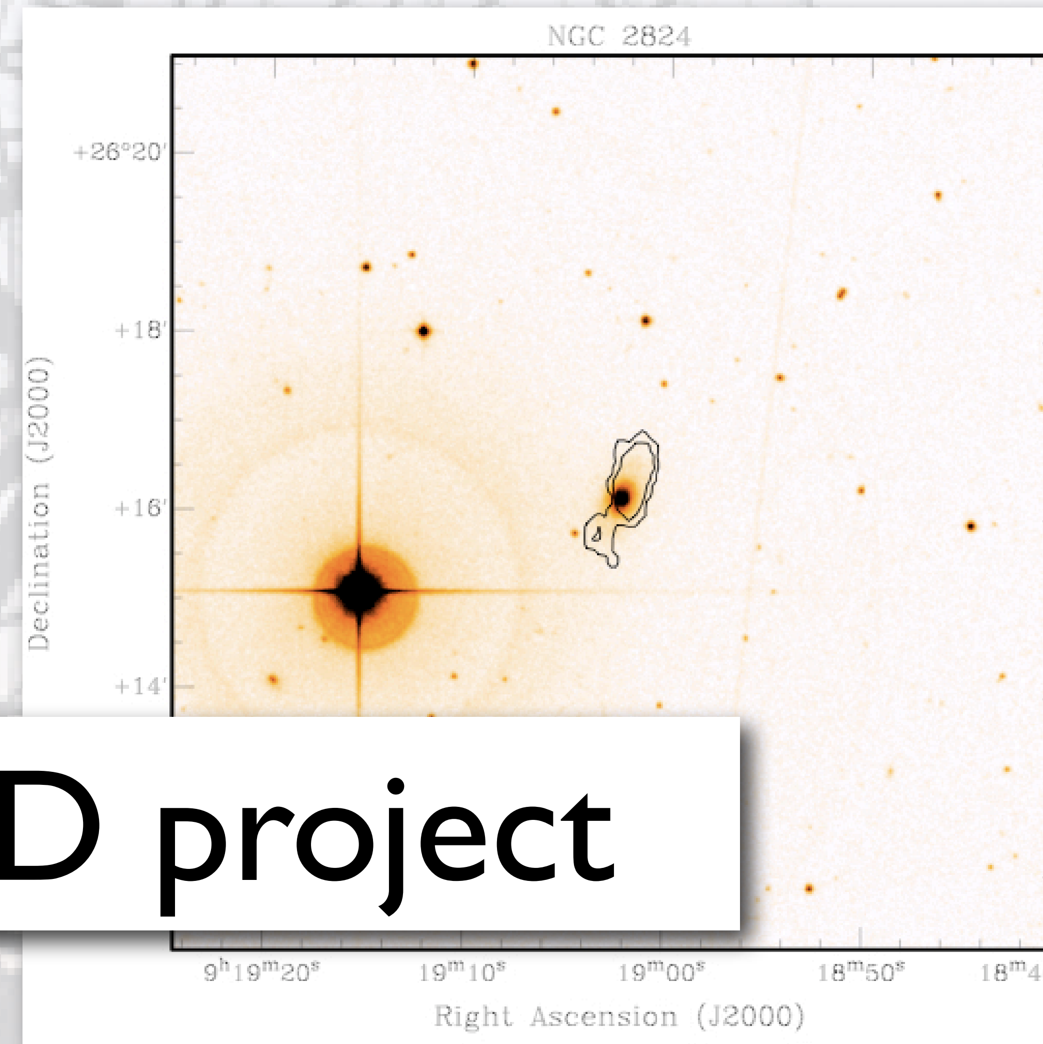
5. Good relation with ionised gas: same structure?

6. Some relation with CO

7. Not clear relation amount of HI ↔ young stars

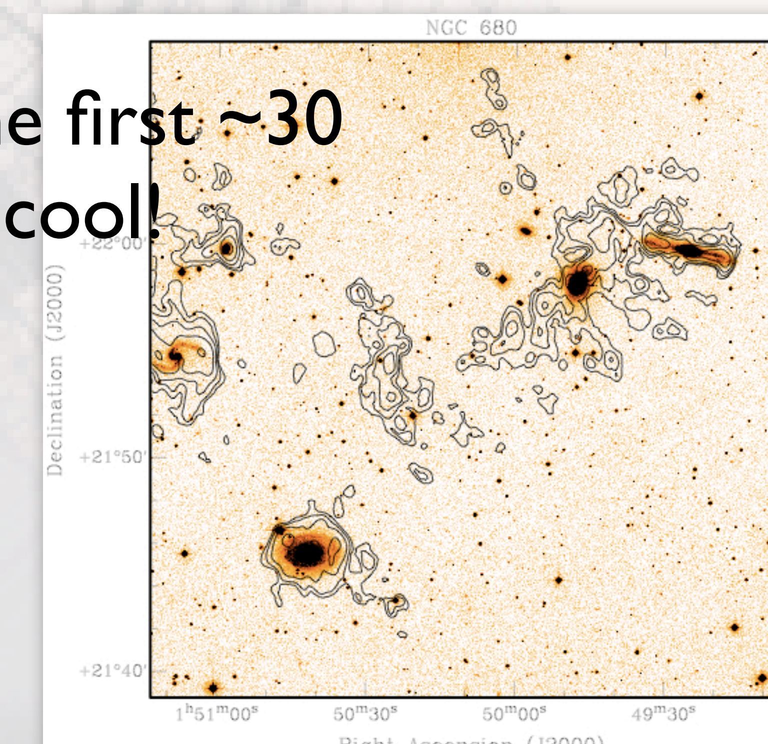
(different type of mergers and/or young stars at large radii)

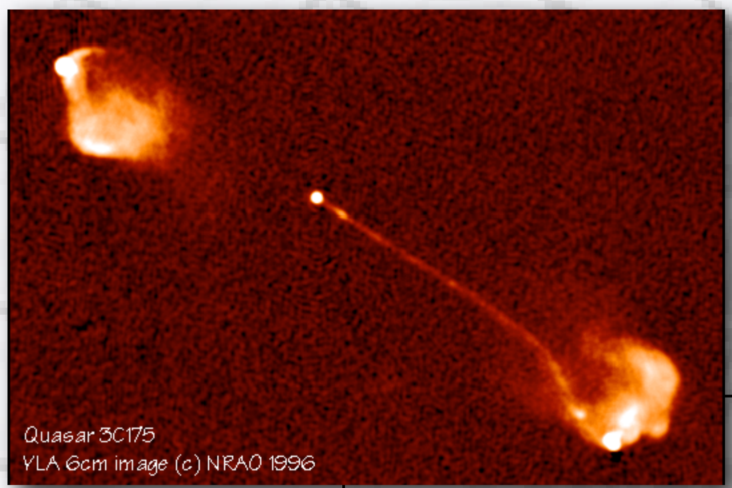


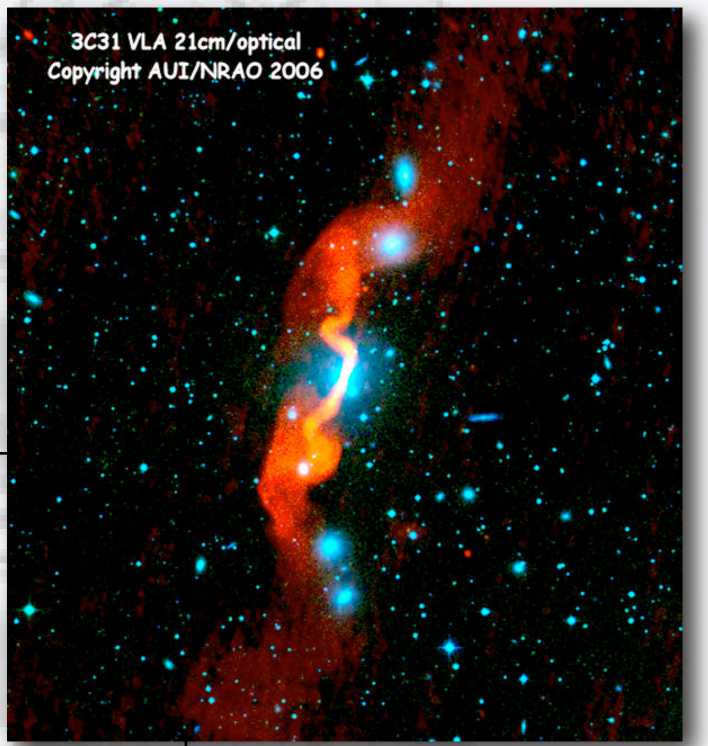


NEXT: ATLAS 3D project

- about 100 *field* early-type galaxies to provide larger statistics
- observations already started
- more than 500 h allocated with the WSRT to do the first ~30 objects and already many new detections.........very cool!







HI and radio galaxies

Again, we use the HI to say something about the origin of the host galaxy and of the activity ⇒ comparison with HI

in “radio quiet” early-type.

⇕

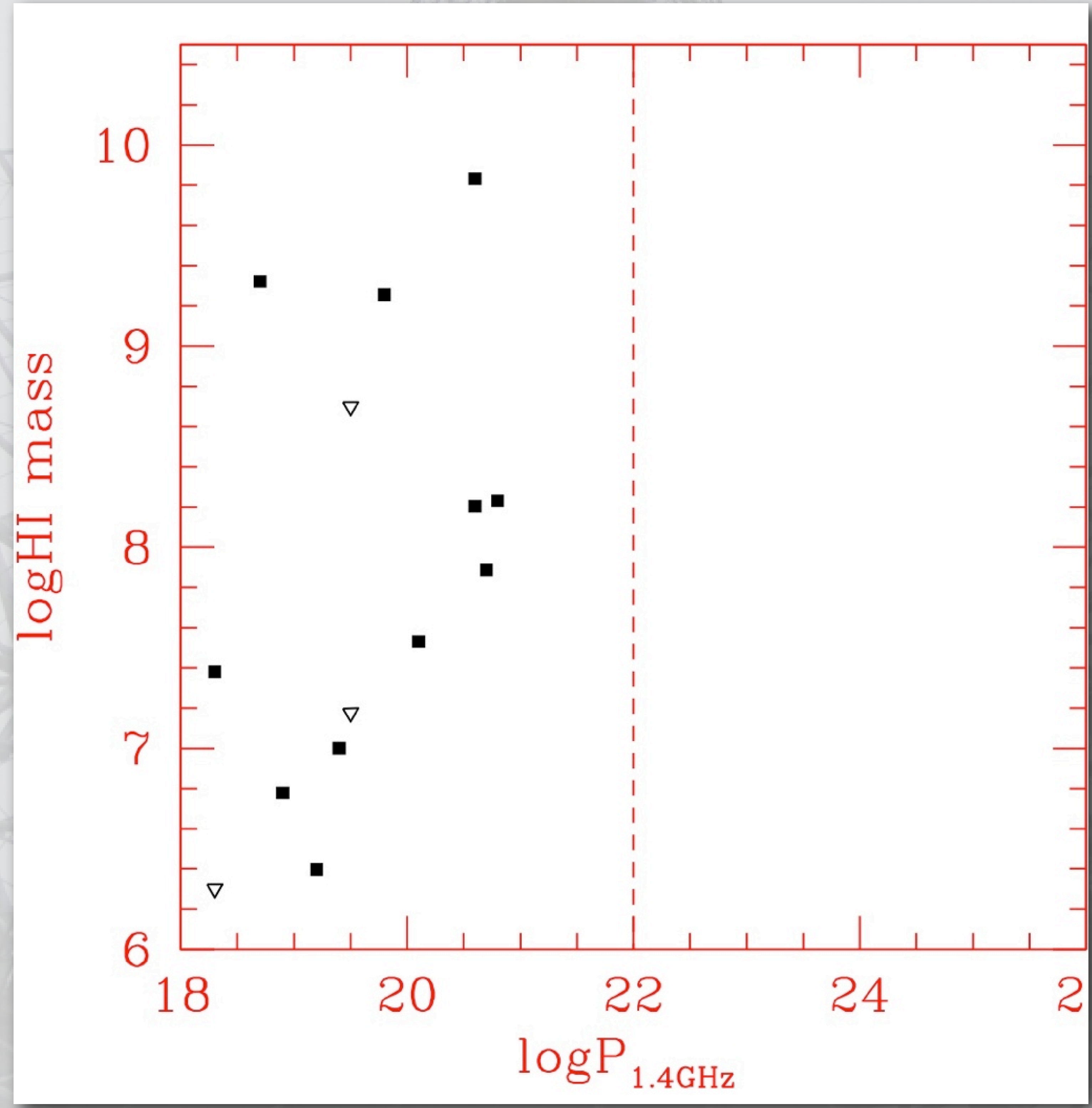
Powerful radio galaxies are claimed to originate from major mergers (e.g. Heckman et al. 1986)

......not clear for lower luminosity radio galaxies

Observations of the nuclear regions using HI in absorption.

HI and radio galaxies

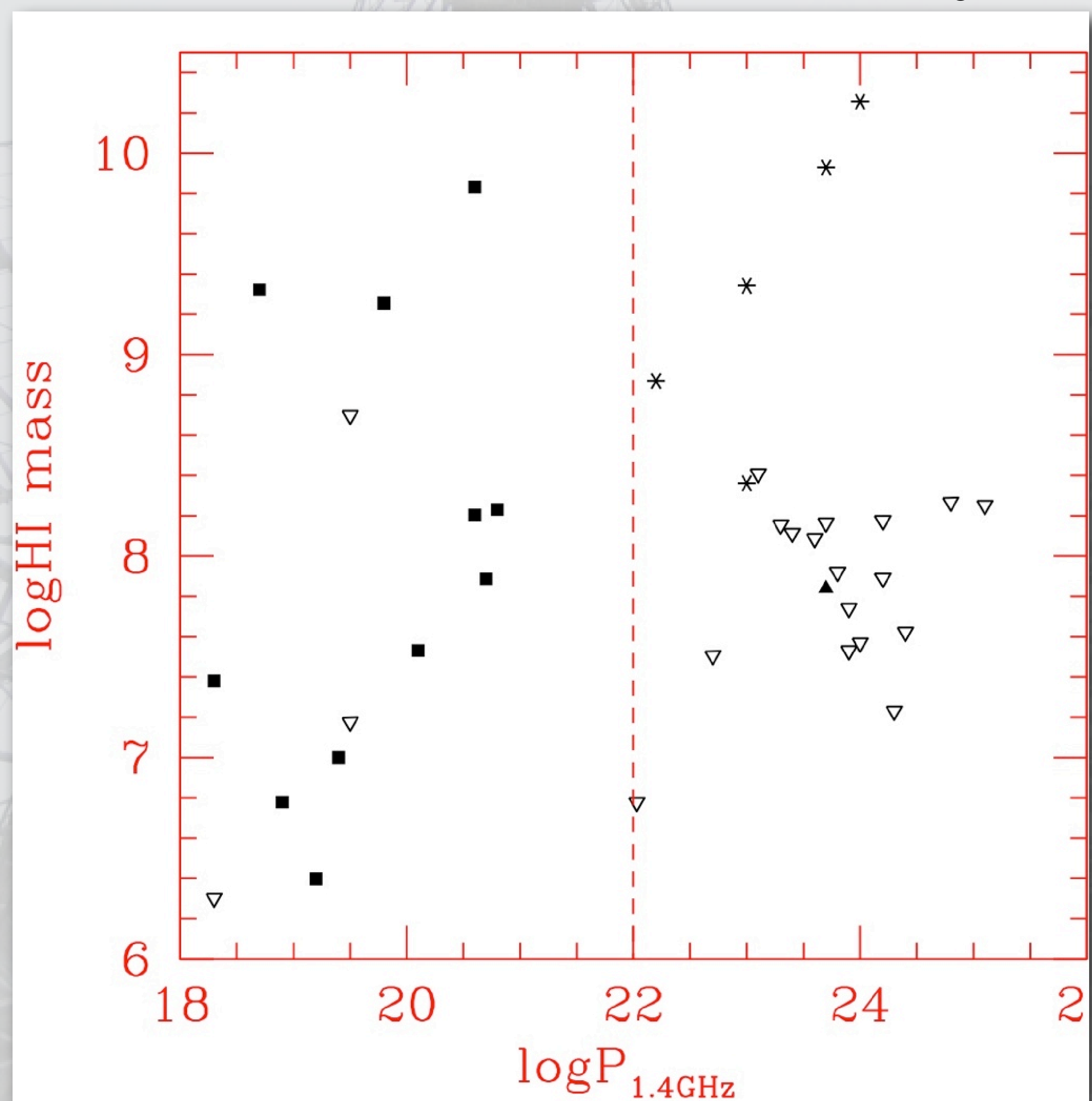
Nearby field early-type galaxies



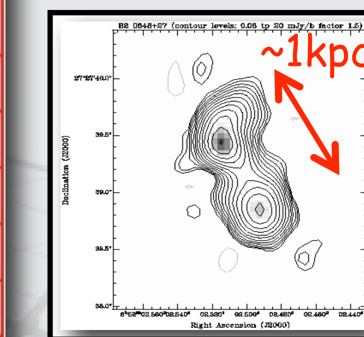
HI and radio galaxies

Nearby field early-type galaxies

Radio galaxies



Compact (young?)

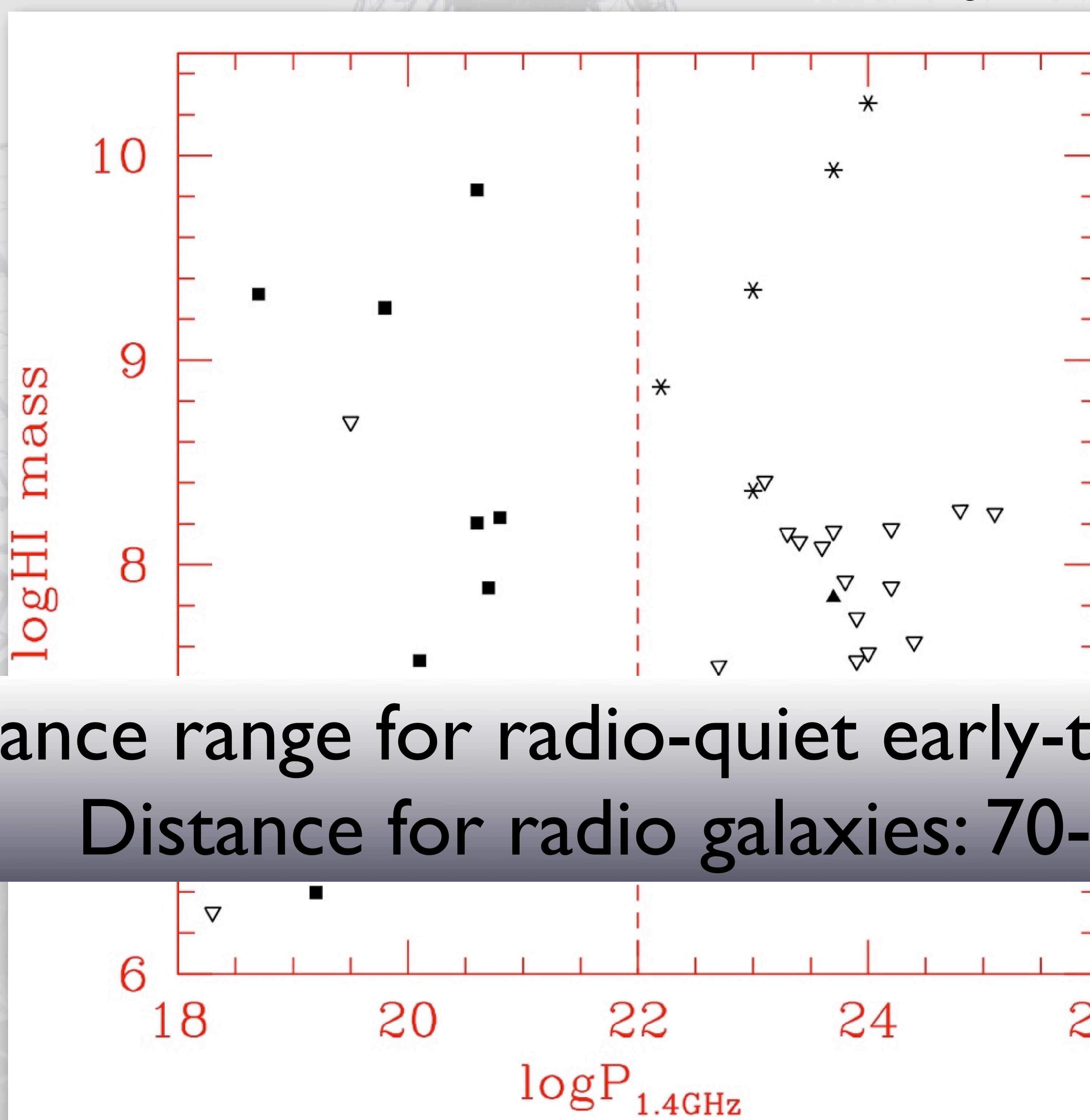


Edge-darkened (Fanaroff-Riley type I) radio galaxies

HI and radio galaxies

Nearby field early-type galaxies

Radio galaxies



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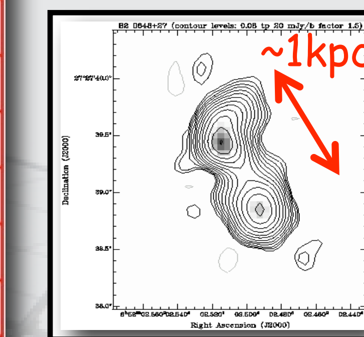

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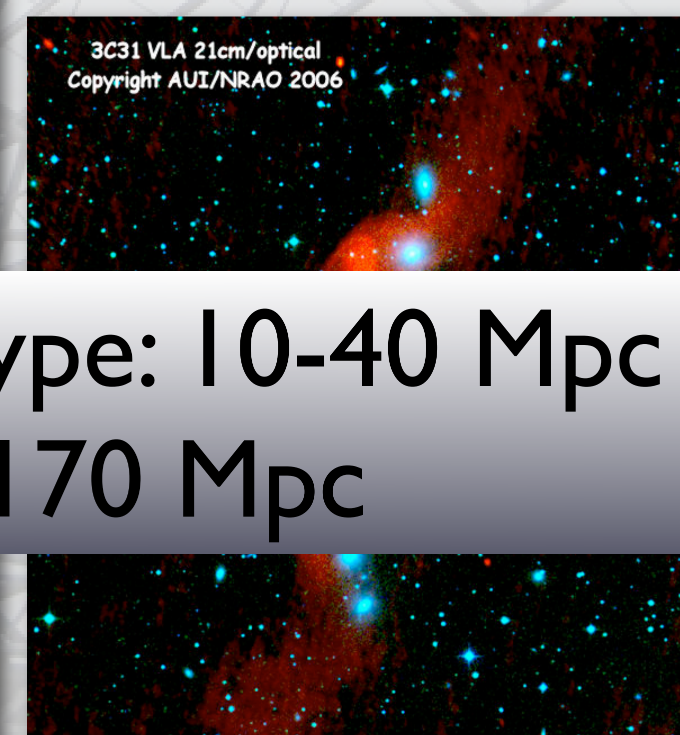
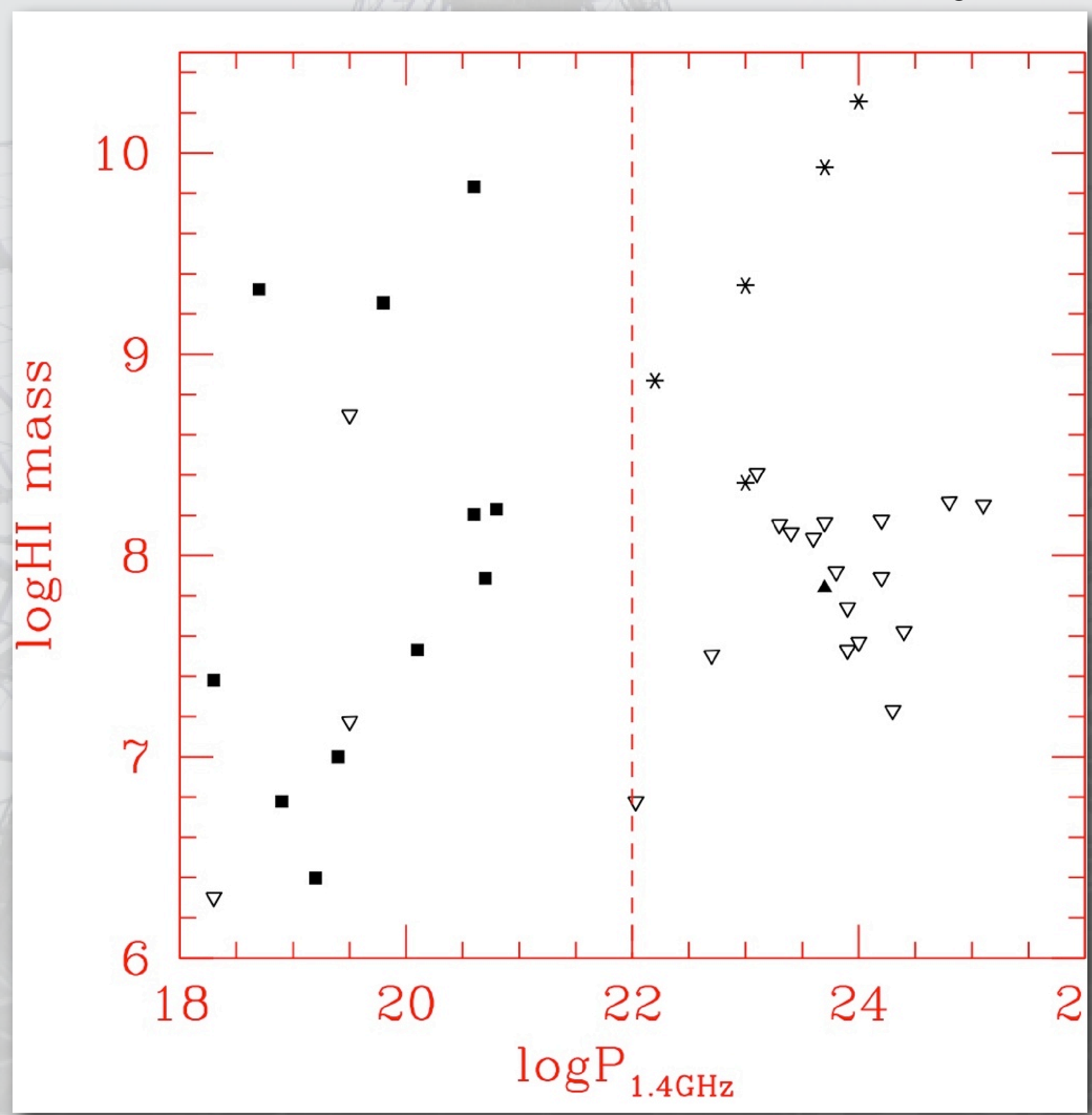


Distance range for radio-quiet early-type: 10-40 Mpc
Distance for radio galaxies: 70-170 Mpc

HI and radio galaxies

Nearby field early-type galaxies

Radio galaxies



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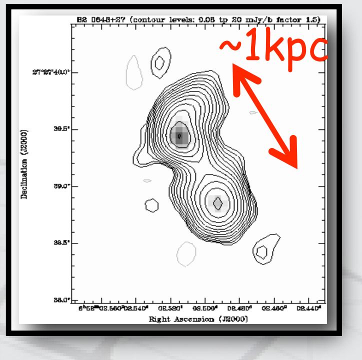
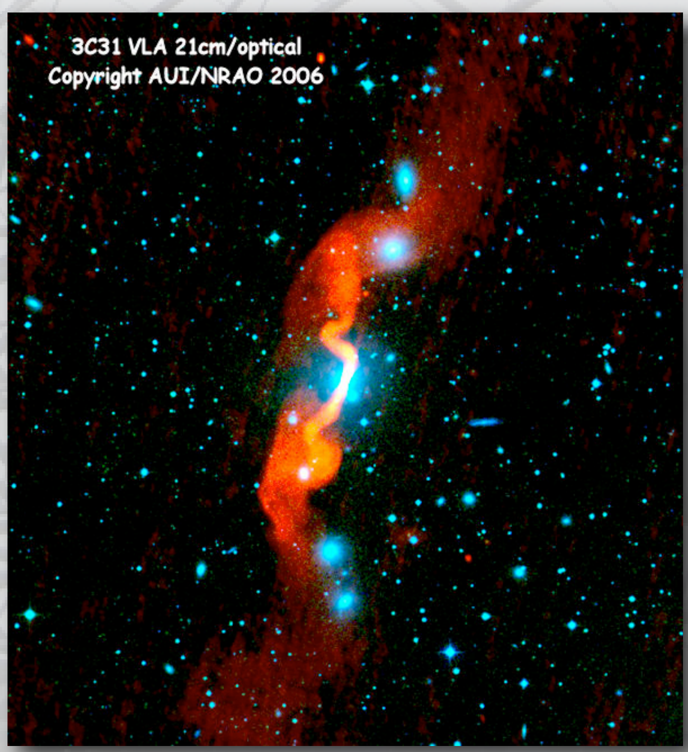


Edge-darkened (Fanaroff-Riley type I) radio galaxies

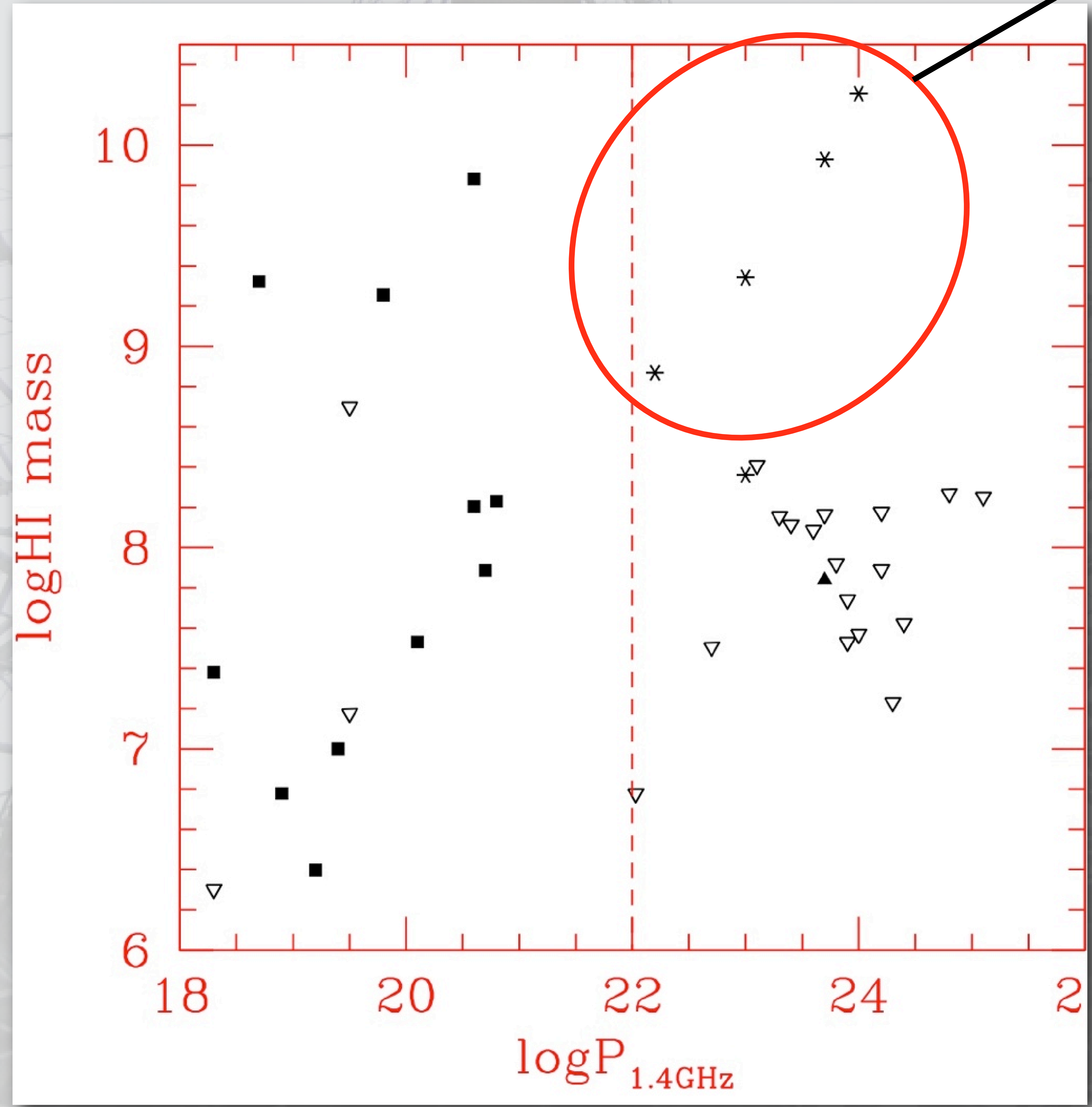


HI and radio galaxies

Also radio galaxies can have large/huge amount of HI

Nearby field early-type galaxies

Radio galaxies



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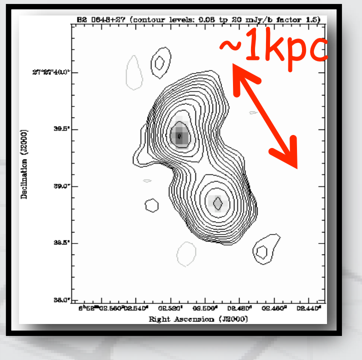
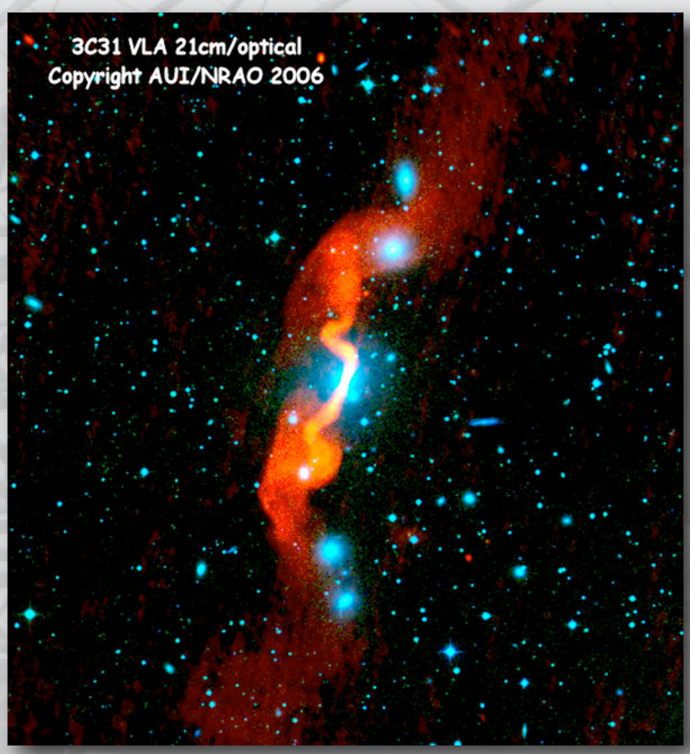


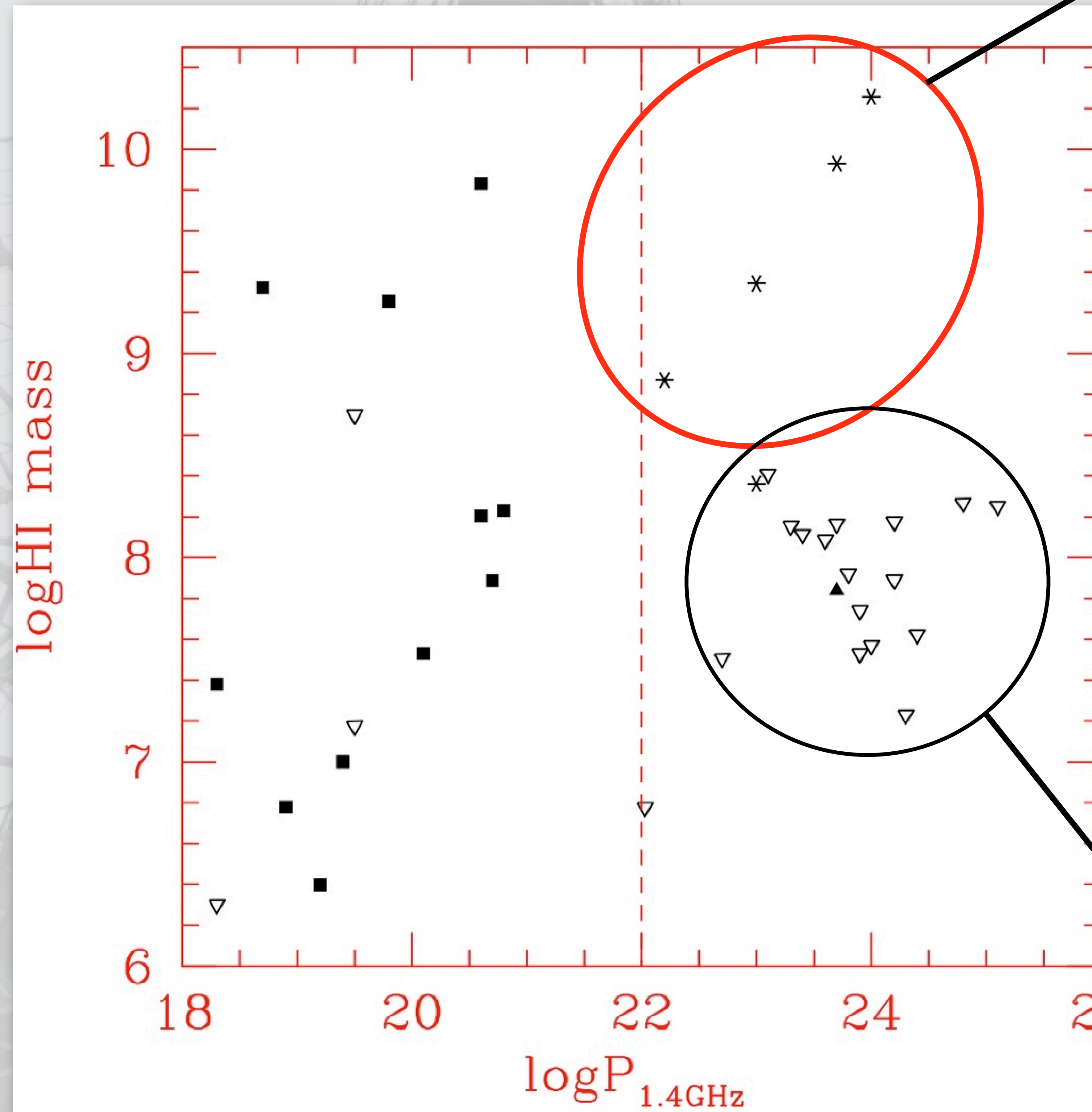
Edge-darkened (Fanaroff-Riley type I) radio galaxies



HI and radio galaxies

Nearby field early-type galaxies

Radio galaxies



Also radio galaxies can have large/huge amount of HI

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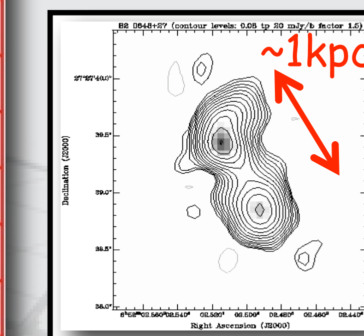


Edge-darkened (Fanaroff-Riley type I) radio galaxies

Great majority of FR I radio galaxies undetected (or very little HI)

Disks in radio galaxies

Remarkable trend:
radio galaxies with large amounts ($M_{HI} > 10^9 M_\odot$) of extended (many tens of kpc up to 200 kpc!) HI disks tend to have a **compact** radio source

⇕

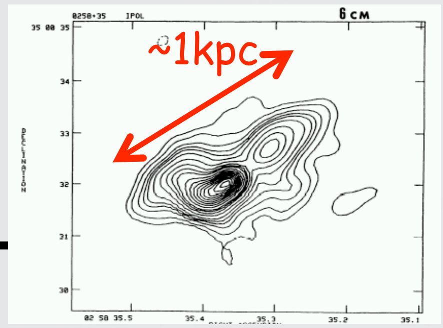
at least some of them are the result of major mergers

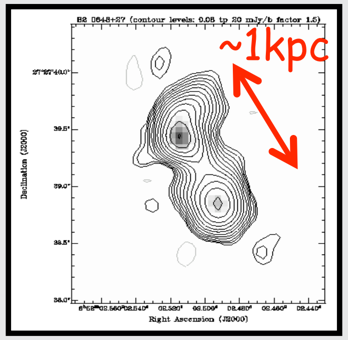
HI-rich compact radio sources **do not grow into extended sources**

either because confined by the ISM in the central region of the galaxy or because the fuel stops before the source expands

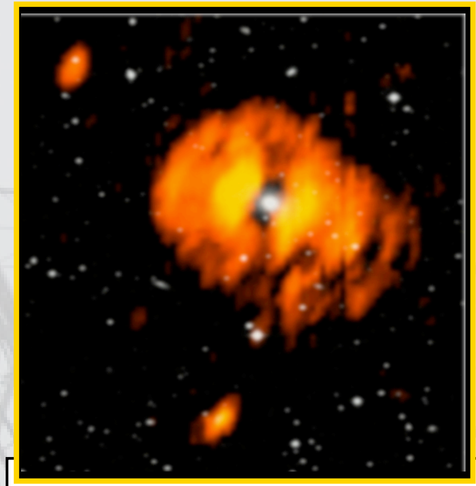
FR I sources not the result of major mergers: small accretion? cooling of hot halo gas?

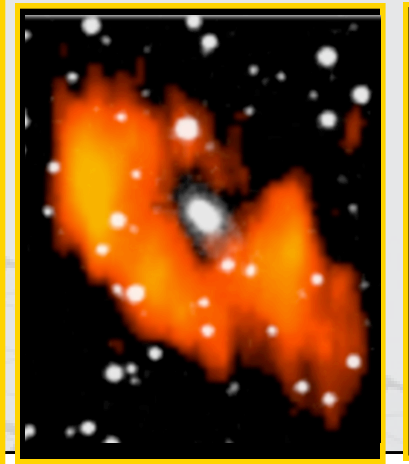
Different for edge-brighten FRII????

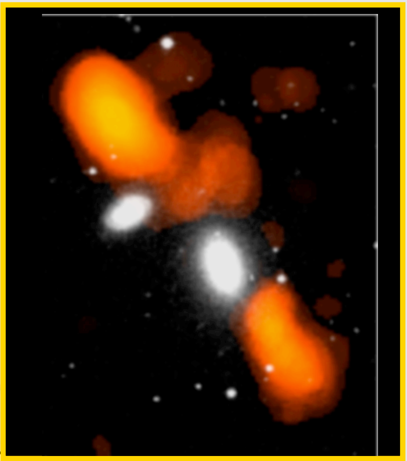


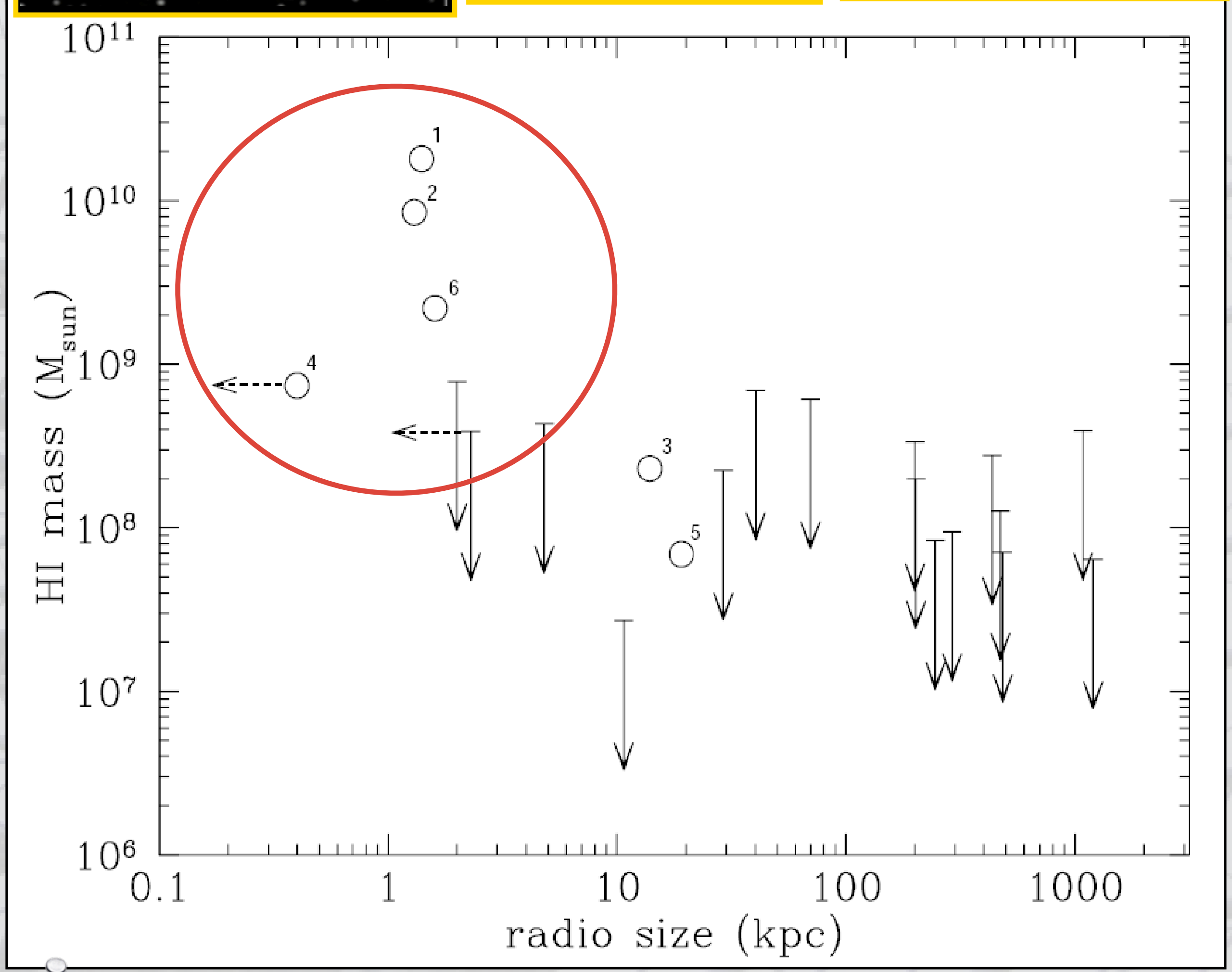


NGC 3894



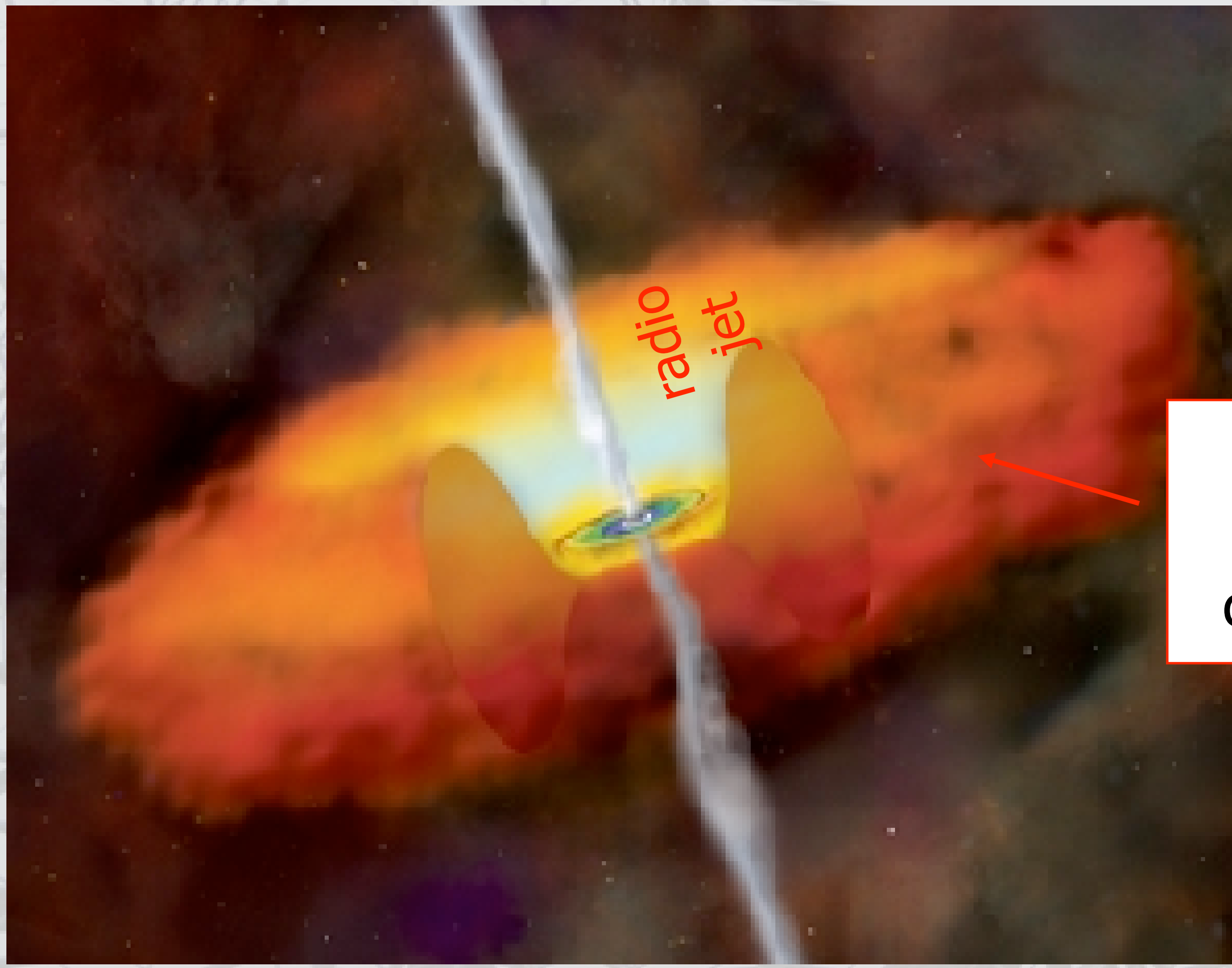




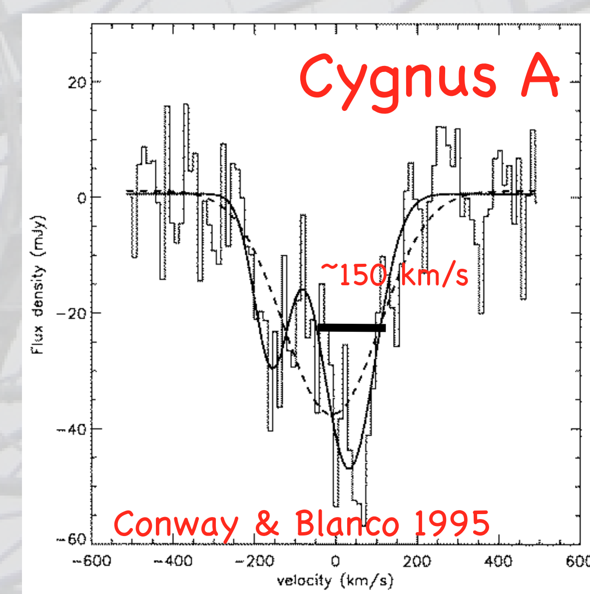


Emonts B., Morganti R., Tadhunter C., Oosterloo T. A&A 2006

The nuclear regions probed by the HI



HI absorption from the torus or from circumnuclear disks



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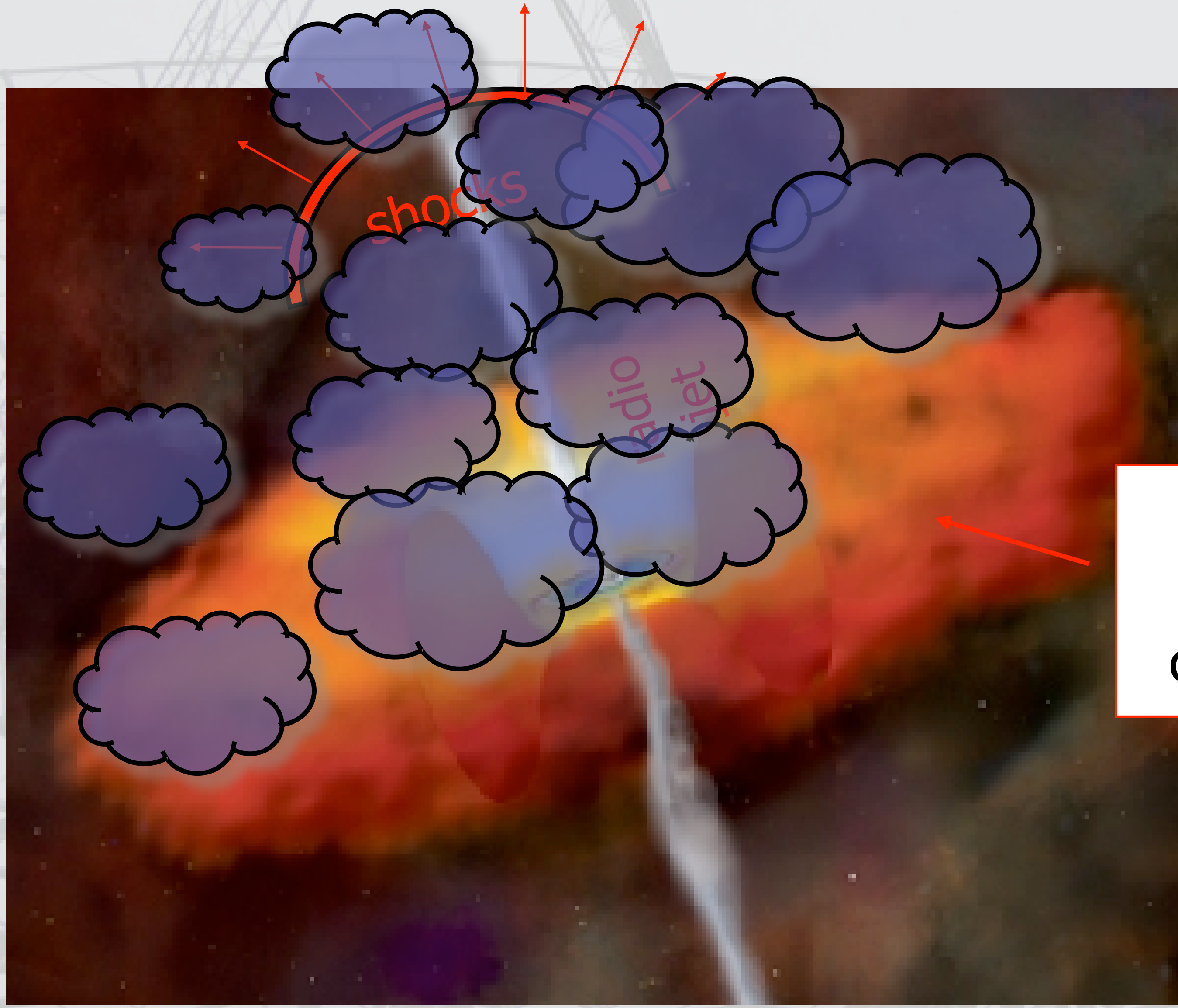

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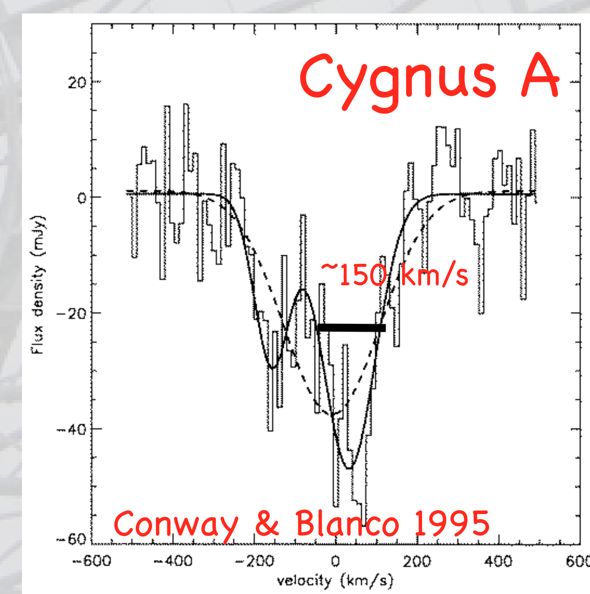
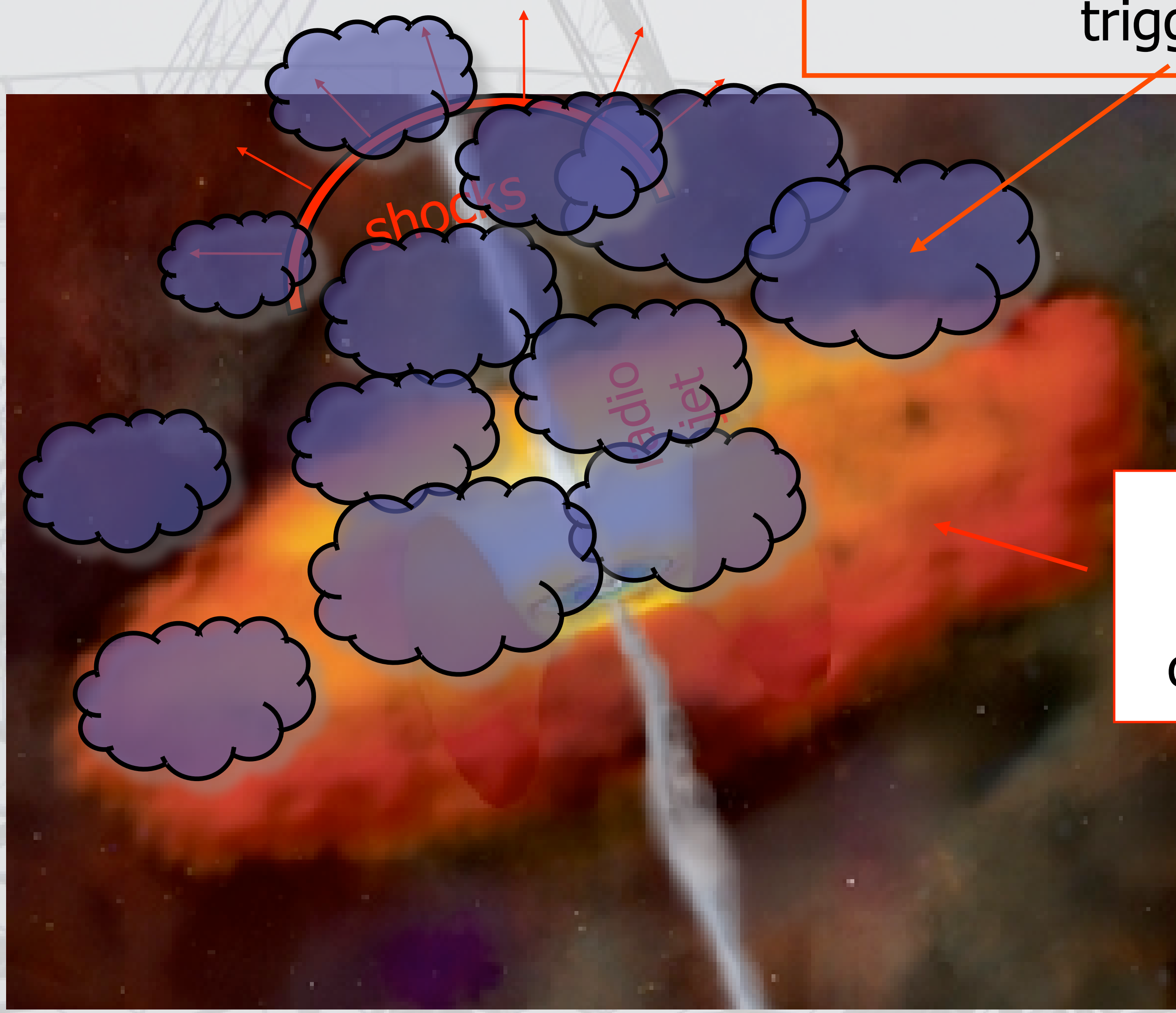


The nuclear regions probed by the HI

extra-gas surrounding the AGN, e.g. left over from the merger that triggered the AGN



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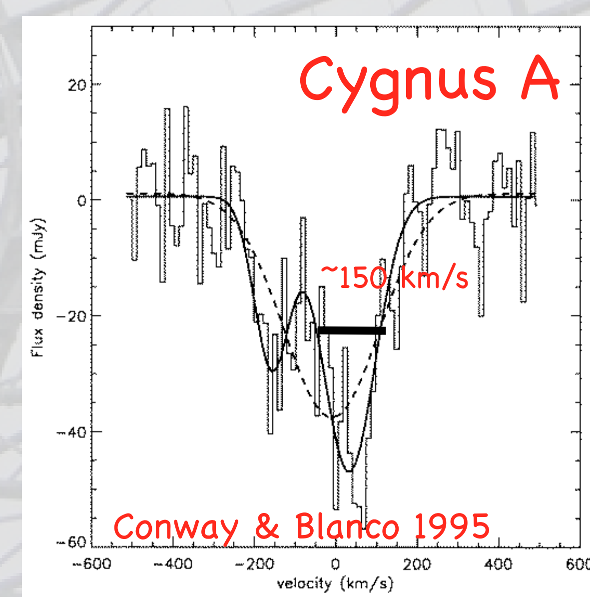

The nuclear regions probed by the HI

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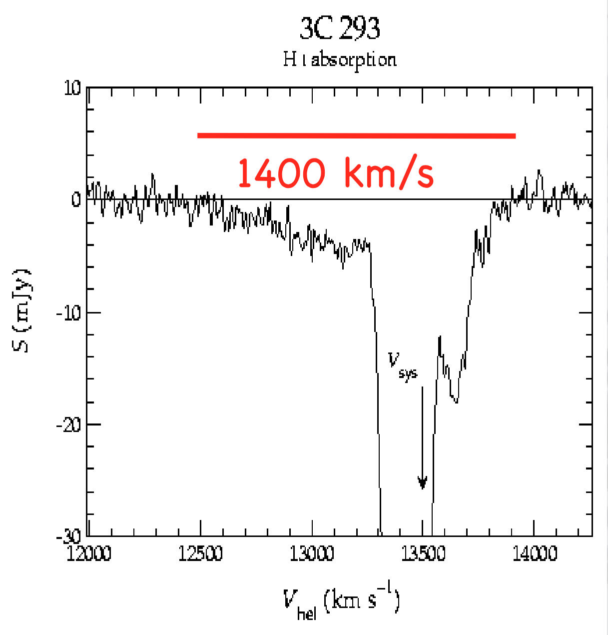
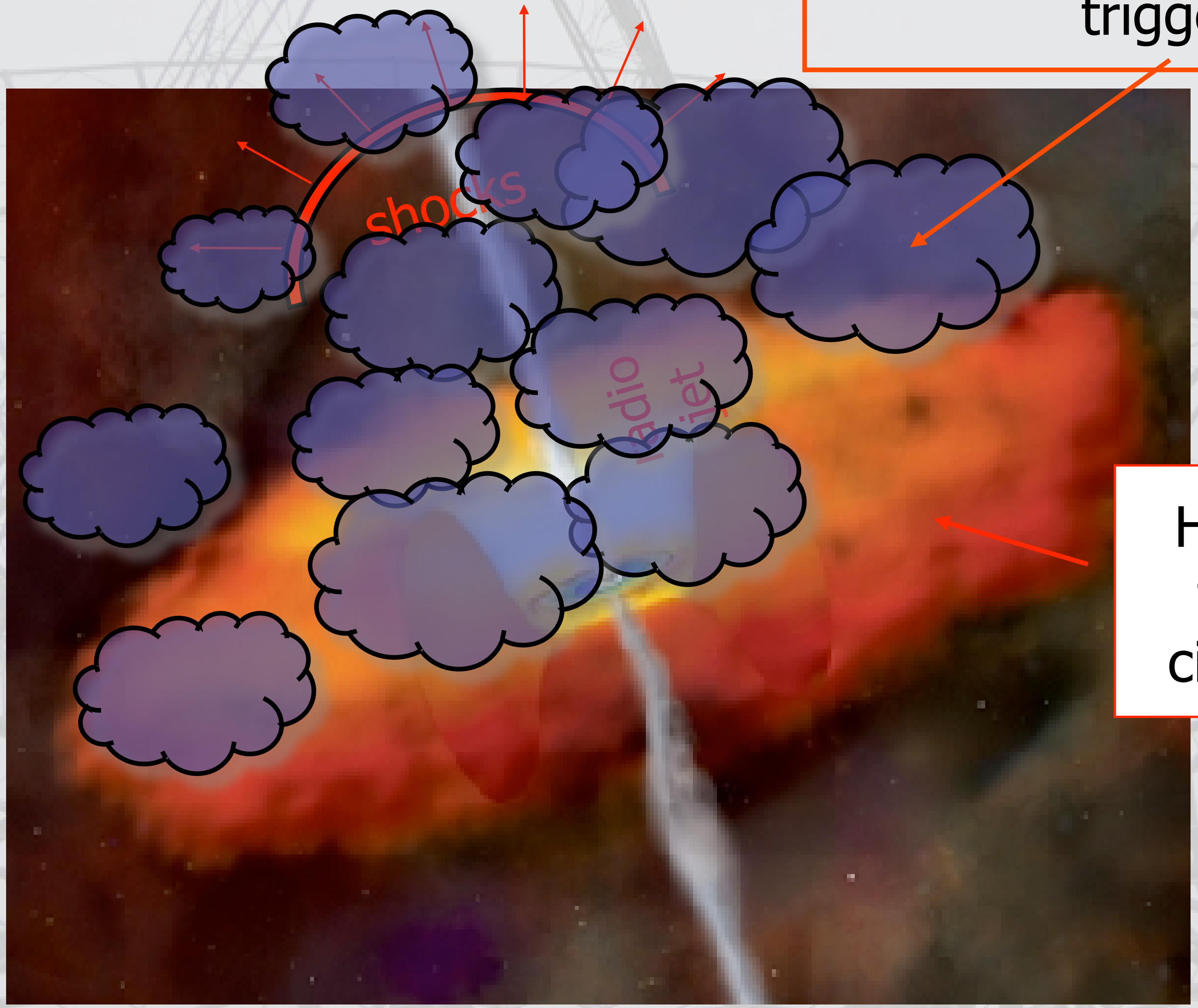
fast HI outflows



WSRT
Morganti et al. 2003



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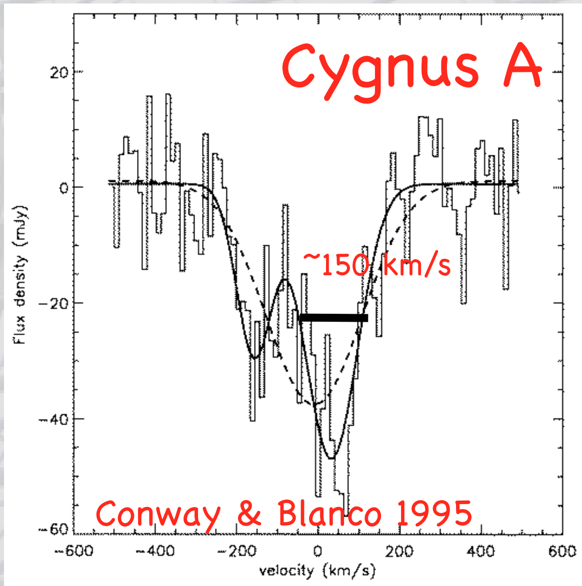
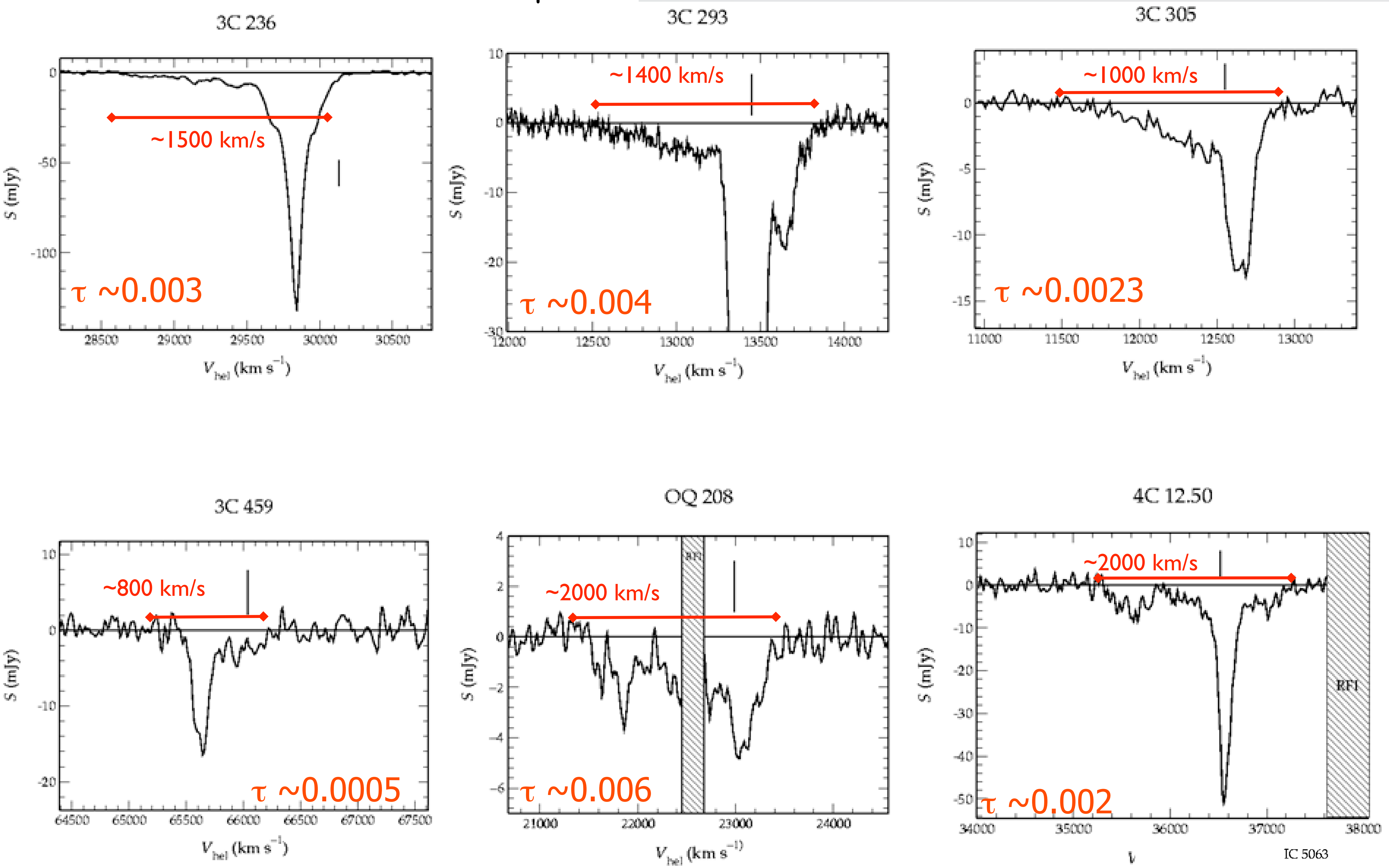


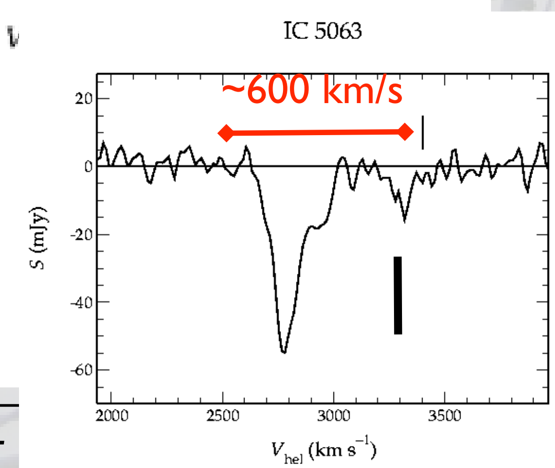
HI in the central regions of radio galaxies (1)

- HI has allowed us to trace *fast outflows*

- Found in *young or recently restarted powerful* radio sources

WSRT observations of broad HI absorption





Up to 2000 km/s width, optical depth <<1%

Column density few times 10^{21} cm^{-2} (for T_{spin} = 1000 K)

Mostly blueshifted HI outflows - Morganti, Oosterloo, Tadhunter A&A 2005

HI in the central regions of radio galaxies (1)

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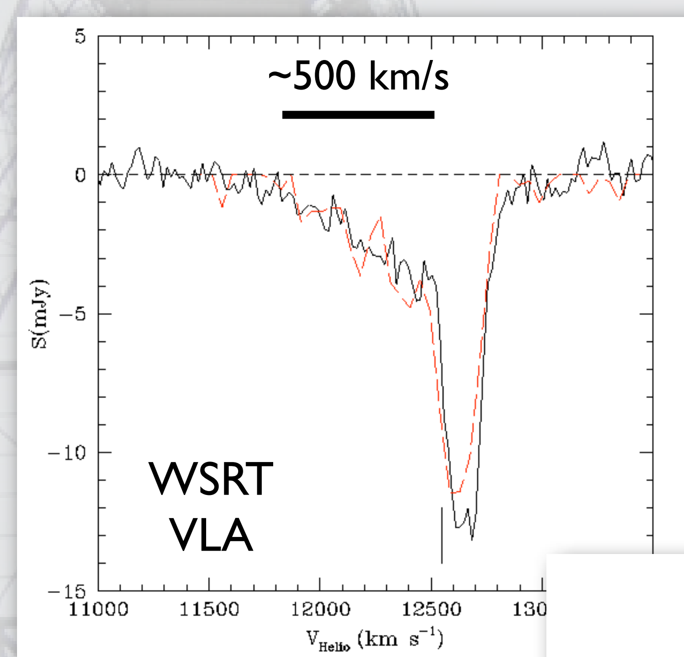
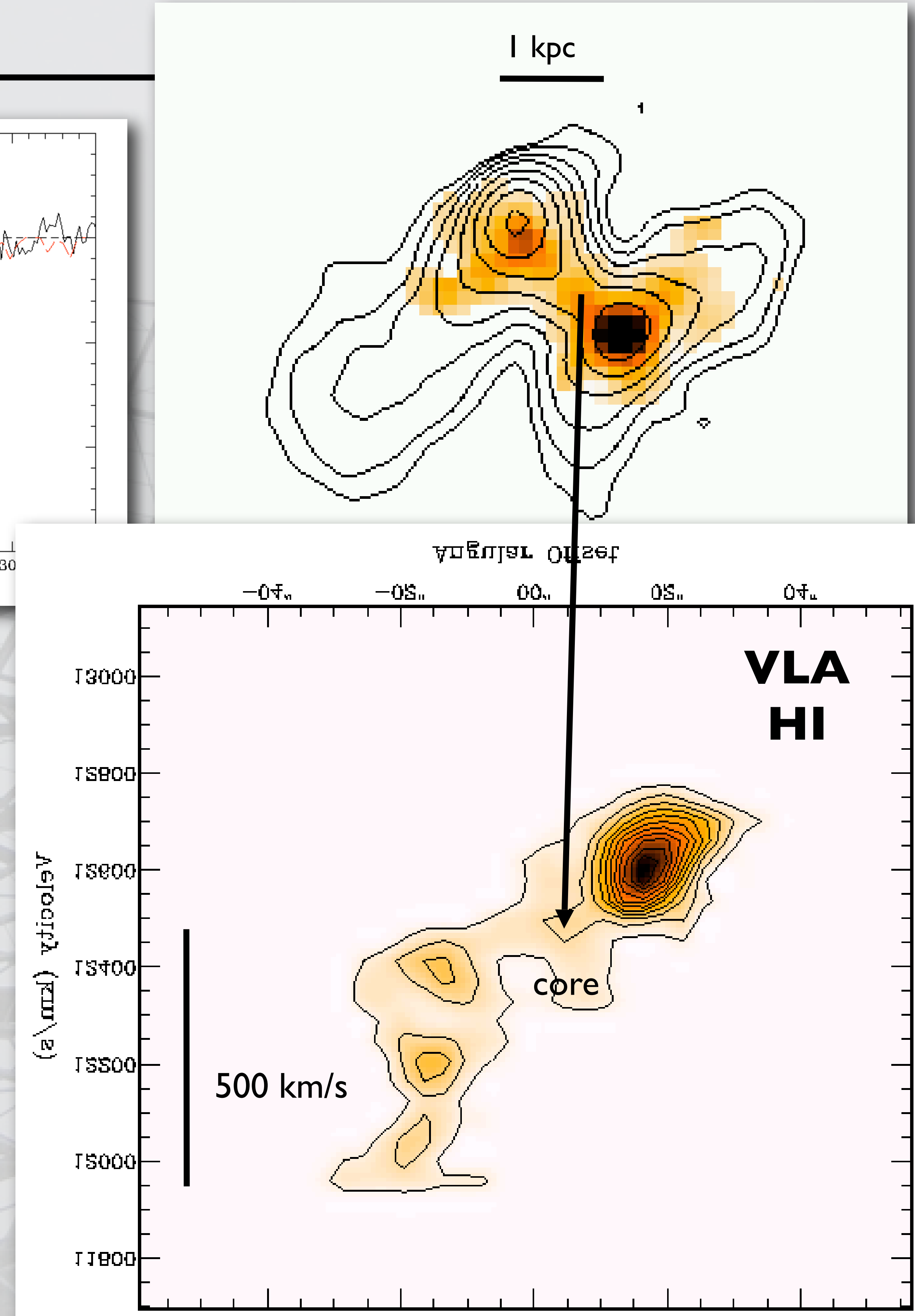
HI in the central regions of radio galaxies (1)

- HI has allowed us to trace *fast outflows*
- Found in *young or recently restarted powerful* radio sources
- Outflows detected in off-nuclear regions: jet-ISM interaction
- Outflows detected (with similar characteristics) both in ionised AND neutral gas!
- Important for feedback?

The case of 3C305





- The broad HI absorption is found **off-nucleus** at the location of the radio lobe (about 1.6kpc from the nucleus)
- Effect of the interaction betwen the radio jet and the rich ISM
- Column density 2×10^{21} cm^{-2} (for T_{spin}=1000K)
- Mass outflowing gas $\sim 10^6$ M_{sun}

Morganti, Oosterloo, Tadhunter, van Moorsel & Emonts 2005 A&A

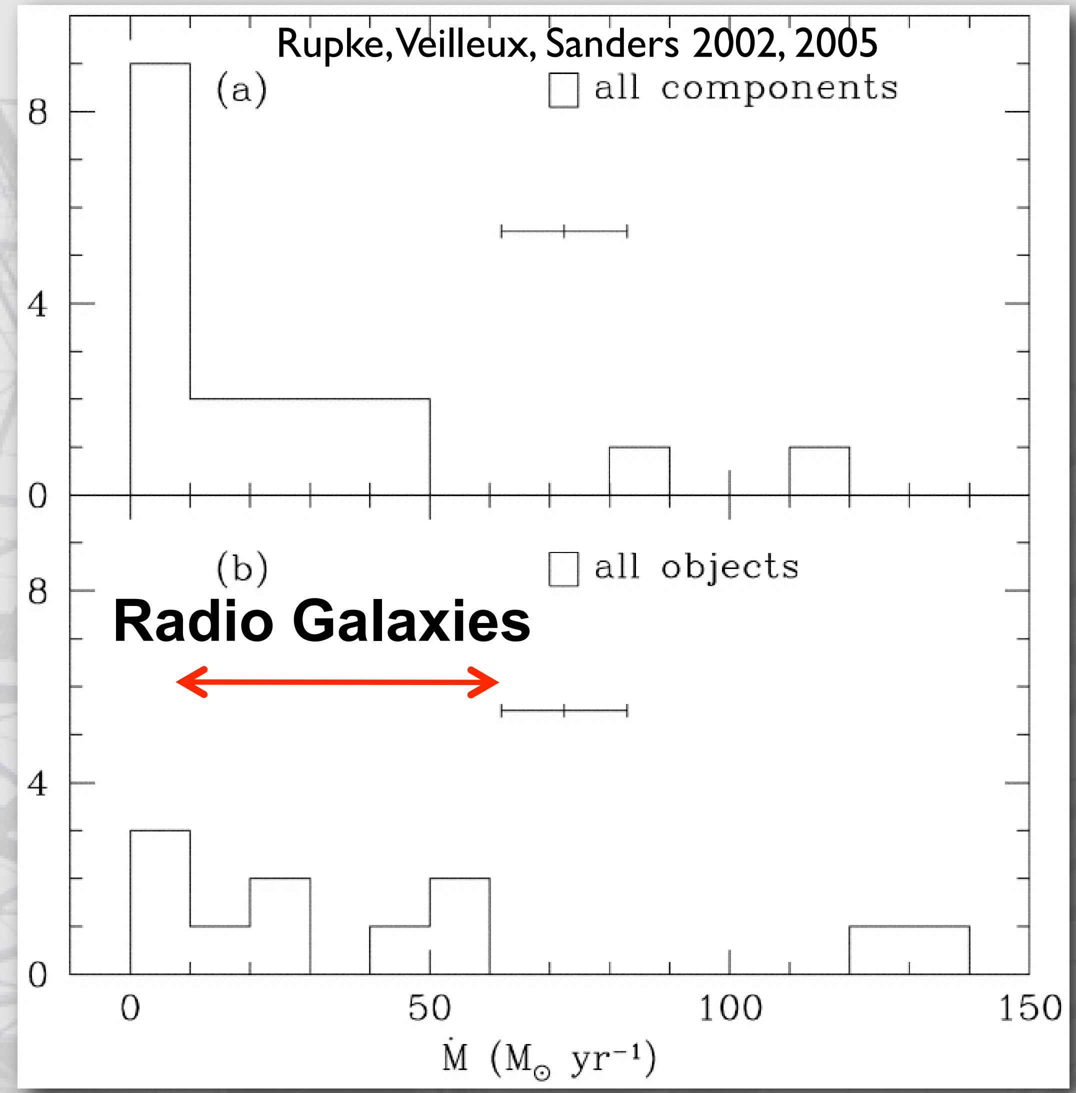
Mass outflow rate

Mass outflow rate between a few and ~50 $M_{\odot}$/yr

comparable (lower end) to that found in Ultraluminous IR galaxies

Relevant impact in the evolution of the galaxy?

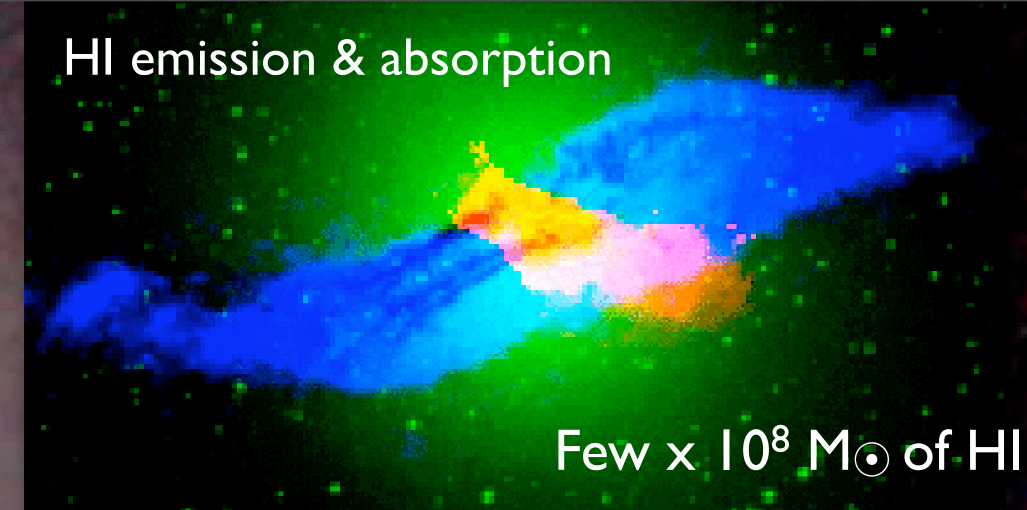
Morganti, Oosterloo, Tadhunter 2005 A&A



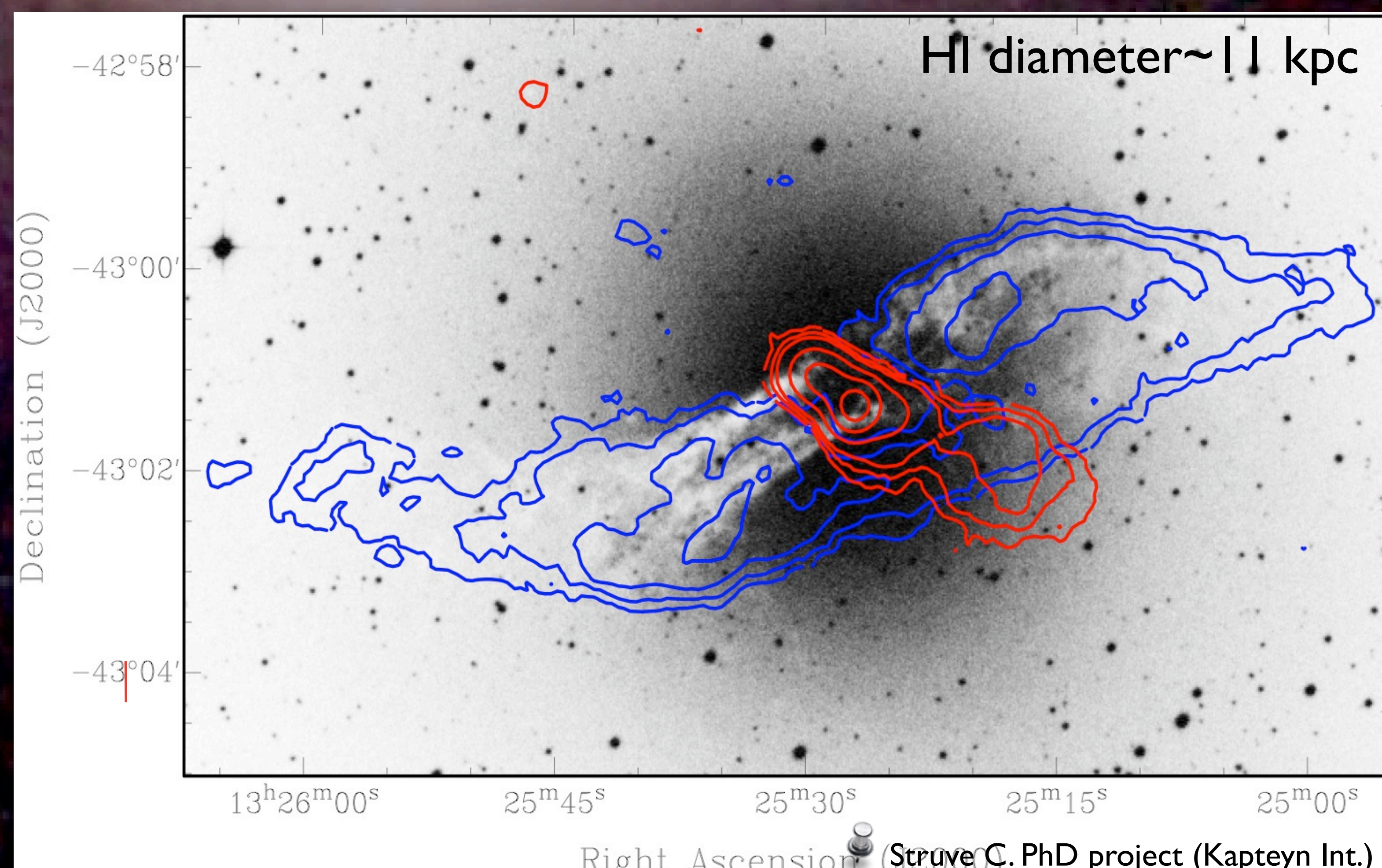
Bulk kinetic energy: ~ few x 10^{57} erg
(over a lifetime of a radio jet)

Jet-driven outflows can have an impact on the evolution of a galaxy comparable to starburst-driven superwinds

HI in the central regions of radio galaxies (2)
The case of Centaurus A



In Cen A, HI was thought to be falling into the nucleus: a case of HI feeding the monster (redshifted HI) BUT....



ATCA observations
6'' resolution ⇒ ~100 pc

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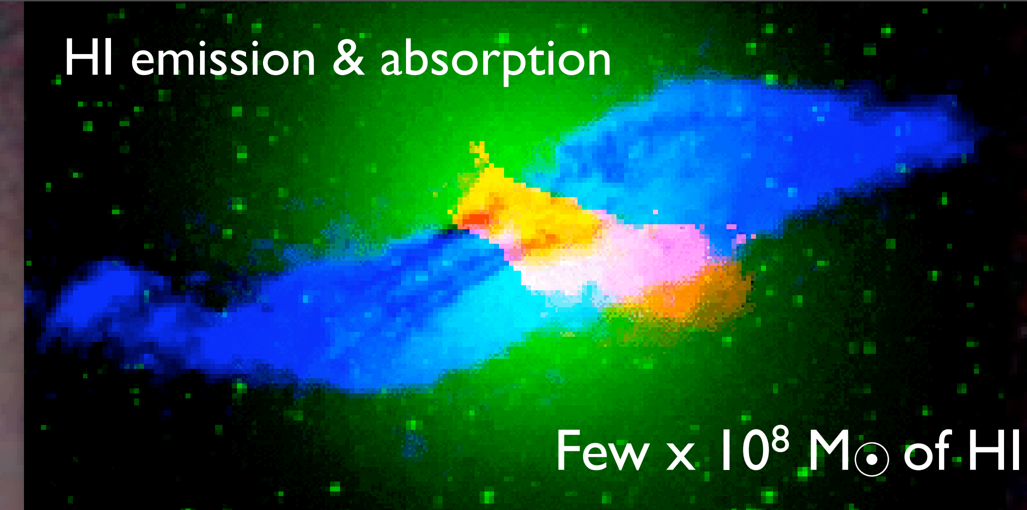

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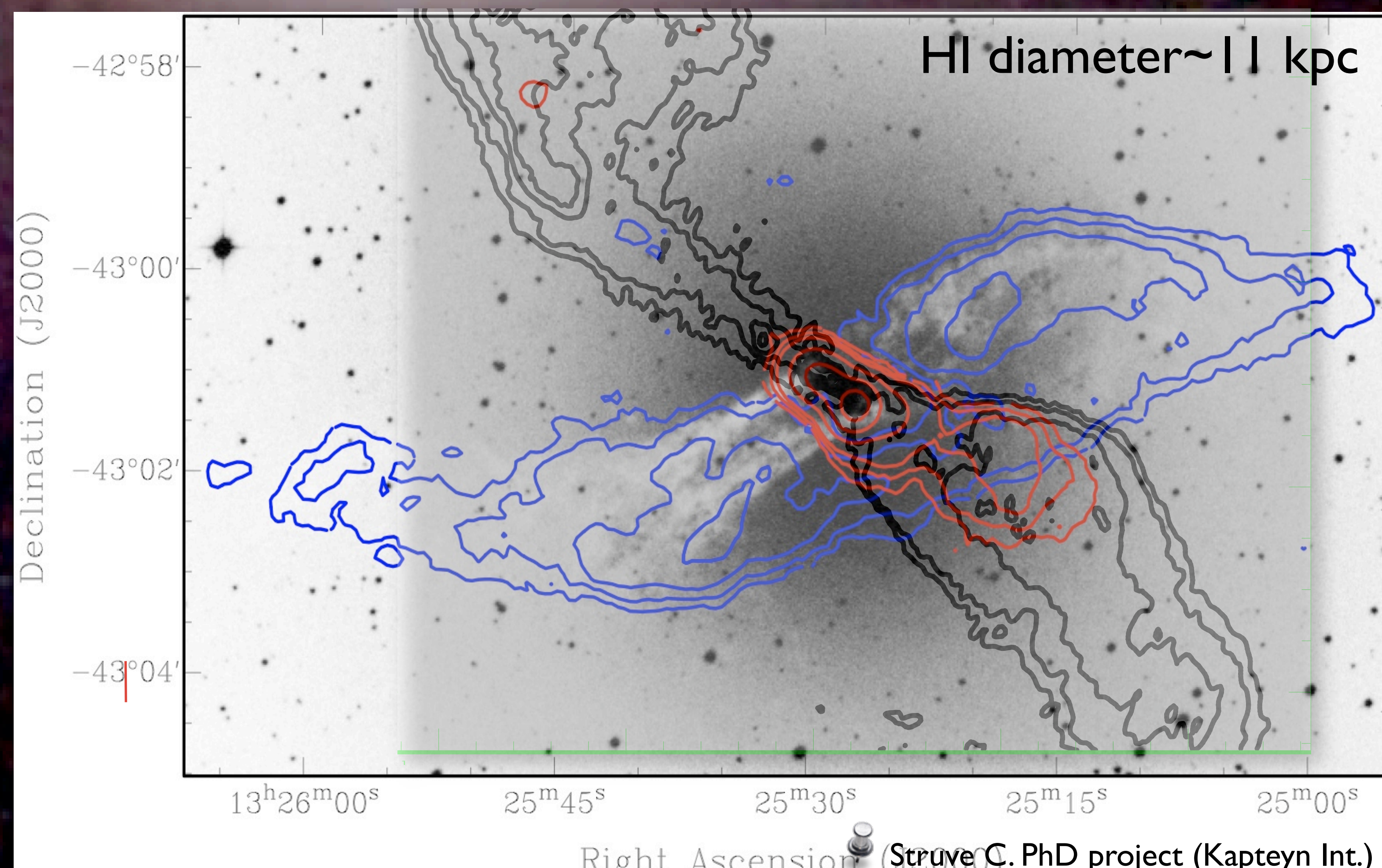

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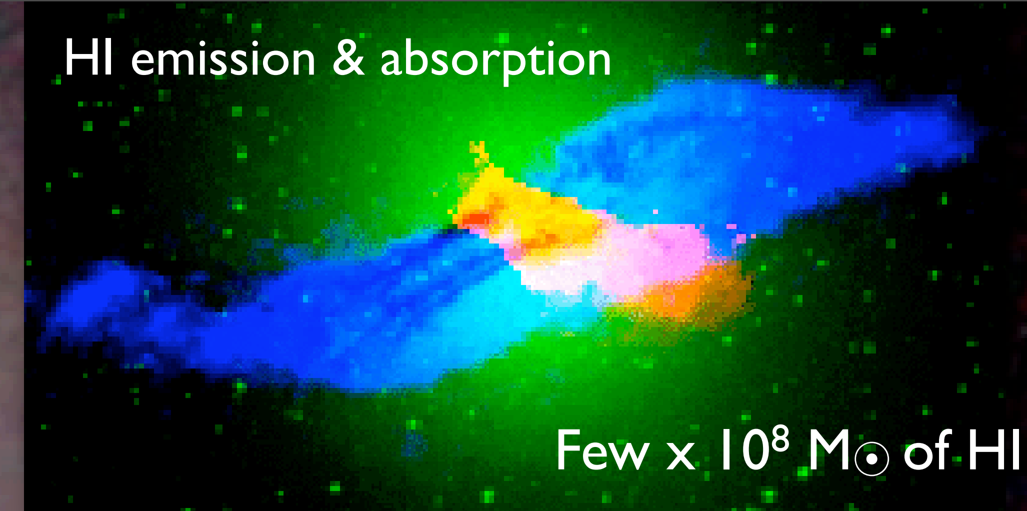

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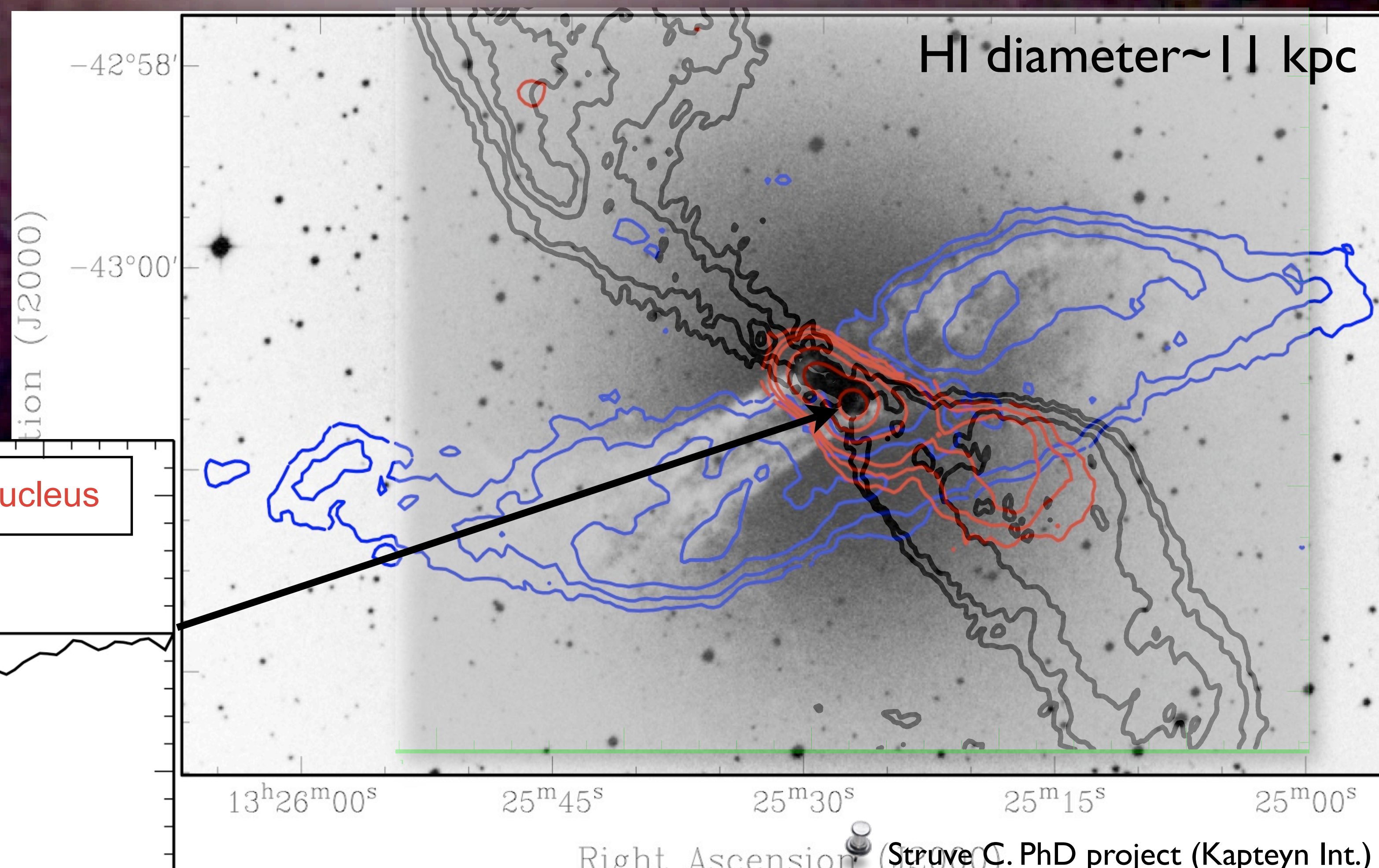

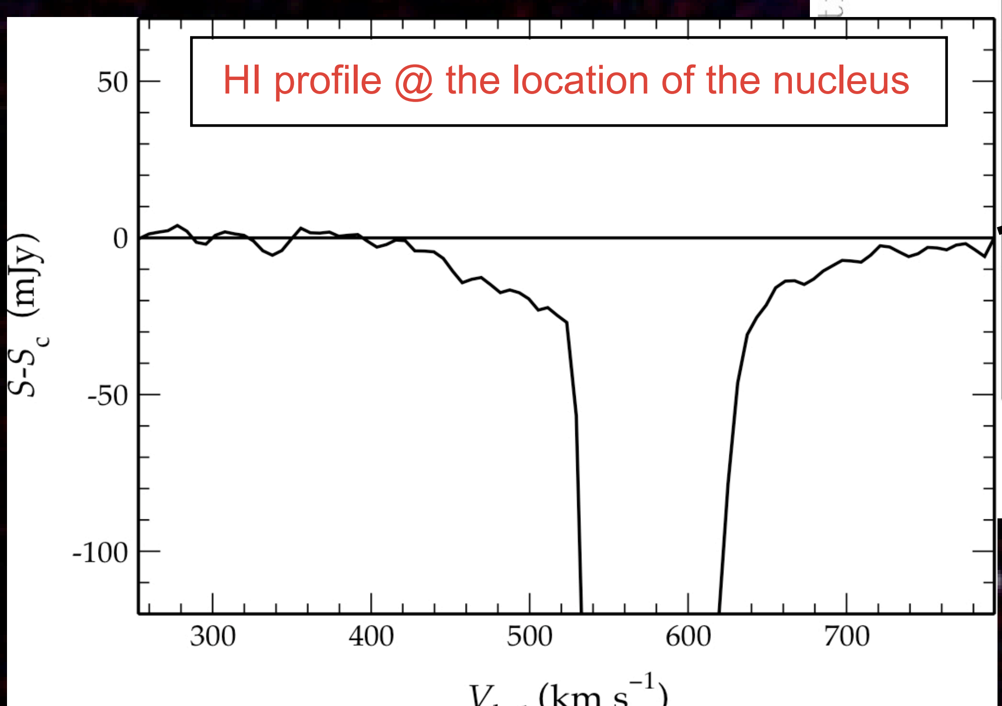

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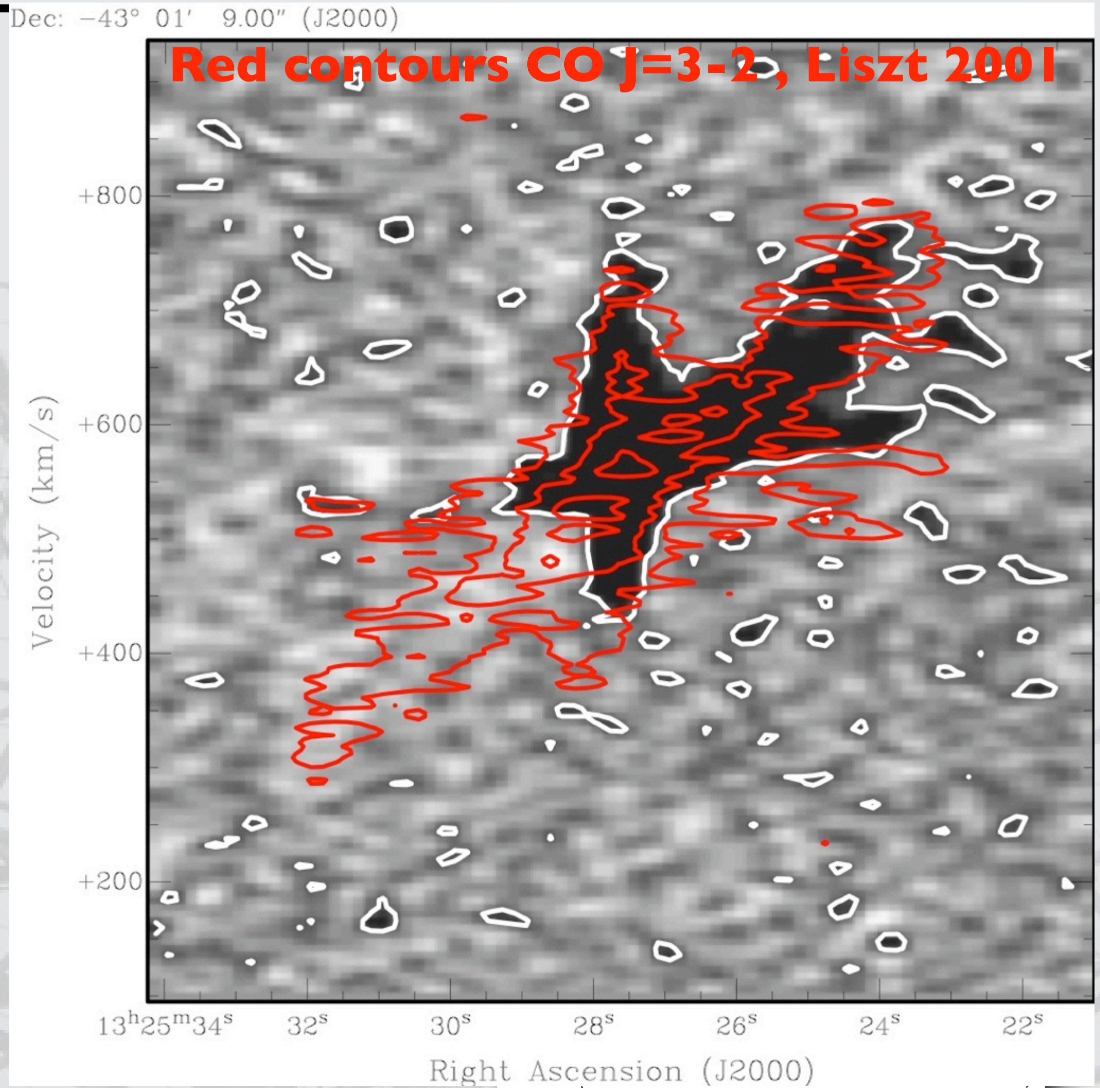
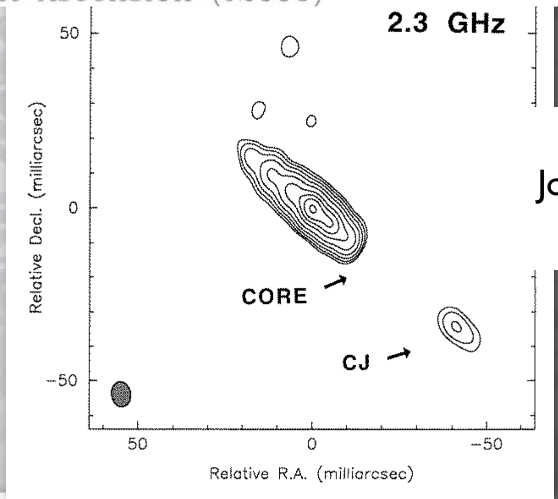
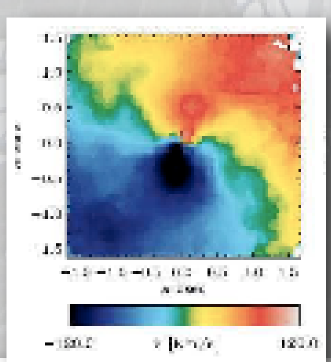
HI counterpart of the nuclear CO disk (~160pc radius)





VLBI image; Jones, Tingay et al 1996

2 arcsec



SINFONI H_2 - Neumayer et al. 2008

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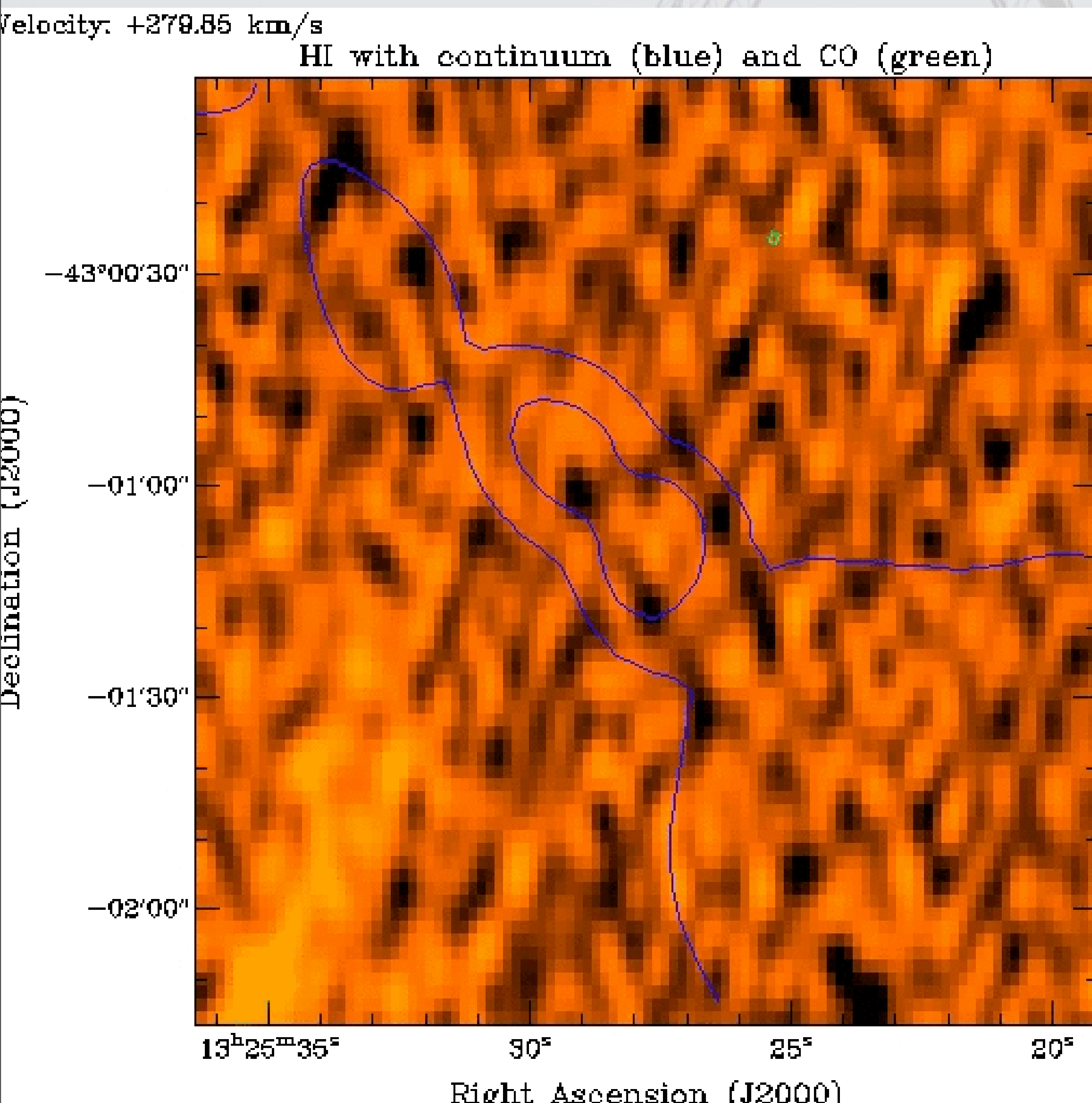

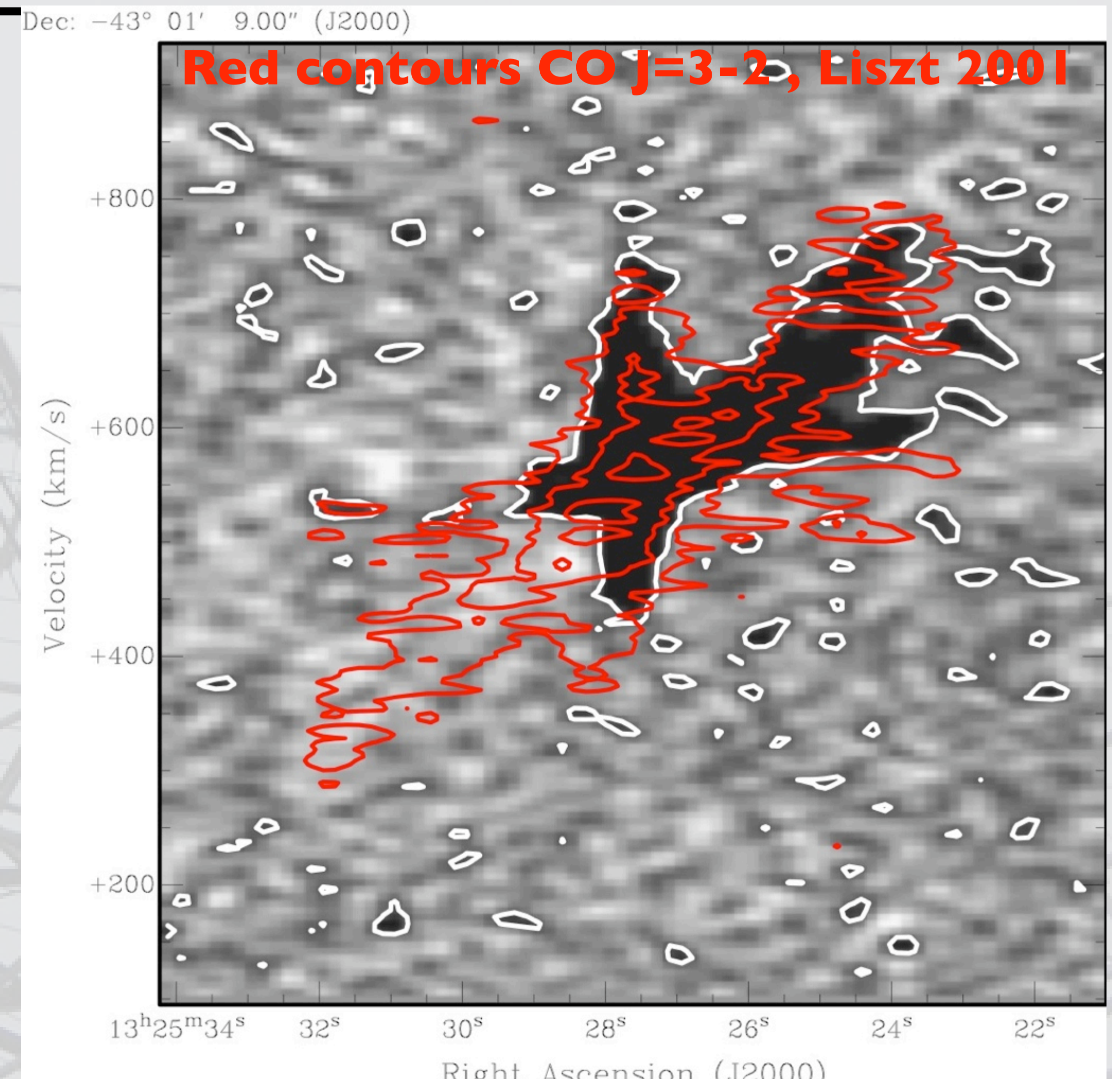

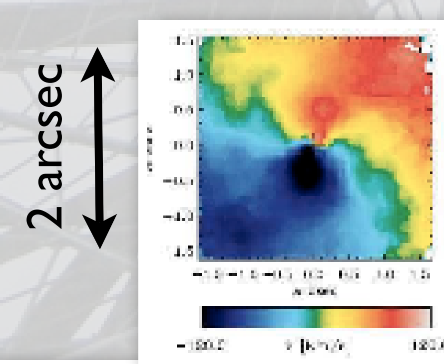

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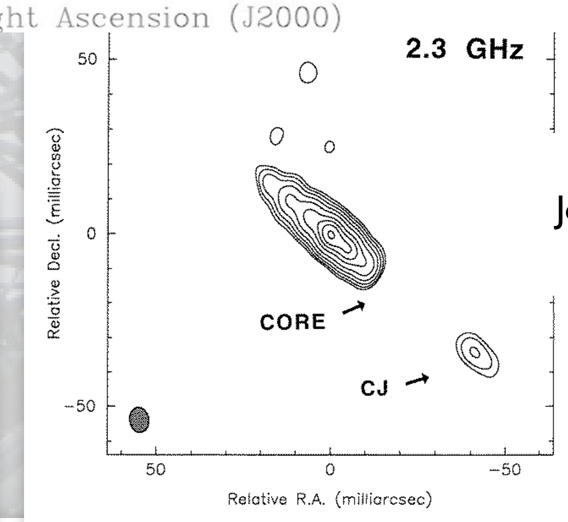

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Jones, Tingay et al
1996

Summary for radio galaxies

• Large amount of HI (large disks) detected but only in compact radio sources.
• Edge-darkened mostly undetected in HI
• How about powerful edge-brighten?

• Surprisingly, jet-driven fast outflows of HI are found in the central regions of young or restarted radio galaxies: impact on the evolution of the host galaxy?

• HI and feeding the monster: we do not see this, even in Cen A!!!

Summary of the first part!

1. HI a *common characteristics* of *field* early-type galaxies if deep enough observations are available

2. HI detected in both E and S0 - a large range of HI masses and morphologies

3. No preference for peculiar galaxies

4. Origin of the HI mainly external: from major mergers to - perhaps - IGM accretion?

5. Good relation with ionised gas: same structure?

6. Some relation with CO

7. Not clear relation amount of HI ↔ young stars

(different type of mergers and/or young stars at large radii)